VTI rapport 594A
Published 2007

www.vti.se/publications

Driver distraction

A review of the literature

Katja Kircher

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Publisher:

SE-581 95 Linköping Sweden

Publication:
VTI rapport 594A

Published:	**Project code:**	**Dnr:**
2007	40658	2006/0226/26

Project:
Inattention and Drowsiness

Author:
Katja Kircher

Sponsor:
IVSS (Project leader: Saab Automobile)

Title:
Driver distraction – A review of the literature

Abstract (background, aim, method, result) max 200 words:

Driver distraction has been defined in many different ways. The most important difference is whether only visual inattention or also cognitive inattention should be included. Many different methods have been used to assess the prevalence and types of driver distraction that occur, and to describe the consequences in terms of driving performance and crash involvement. There is strong agreement that distraction is detrimental for driving, and that the risk for crashes increases. Drivers rather opt for repeated glances instead of extending one single glance, if the secondary task demands attention for a longer period of time. However, repeated glances have more detrimental effects on driving performance than a single glance of the same duration as one of the repeated glances. Only recently the method of remote eye tracking has emerged, which enables real time identification of visual distraction. So far this method has mostly been used in driving simulators. Different algorithms that diagnose distracted drivers have been tested with promising results. In simulators it is difficult, however, to induce true distraction, due to the short duration of the experiment and the artificial setting. A prolonged field study under naturalistic conditions could provide new insights and validation of simulator studies.

Keywords:
distraction, eye movements, countermeasure, field study

ISSN:	**Language:**	**No. of pages:**
0347-6030	English	58

Utgivare:	Publikation: VTI rapport 594A		
vti 581 95 Linköping	Utgivningsår: 2007	Projektnummer: 40658	Dnr: 2006/0026-26
	Projektnamn: Distraktion och sömnighet		
Författare: Katja Kircher	Uppdragsgivare: IVSS, Projektledare Saab Automobile		

Titel:
Förardistraktion – En litteraturstudie

Referat (bakgrund, syfte, metod, resultat) max 200 ord:

Förardistraktion har definierats på många olika sätt. Den största skillnaden är om enbart visuell distraktion eller också kognitiv distraktion innefattas. Många olika metoder har använts för att undersöka förekomst och typer av förardistraktion och för att beskriva konsekvenserna med avseende på förarbeteende och olycksinblandning. Det råder enighet om att distraktion försämrar körprestationen och att olycksrisken stiger. Förarna väljer hellre att titta bort från vägen flera gånger istället för att titta bort en gång under en längre stund om sekundäruppgiften kräver uppmärksamhet över en längre tidsperiod. Upprepade blickar bort från vägen leder emellertid till sämre körprestation än en enda blick av samma längd som en av de upprepade blickarna. På senaste tiden har metoden att mäta ögonrörelser kontaktfritt dykt upp, vilken möjliggör identifikation av förardistraktion i realtid. Hittills har denna metod använts mestadels i körsimulatorer. Olika algoritmer som diagnostiserar förardistraktion har undersökts med lovande resultat. I körsimulatorer är det däremot svårt att få fram naturlig distraktion hos föraren, eftersom experimenten vanligtvis är förhållandevis korta och hela situationen är onaturlig. En längre fältstudie under naturliga betingelser skulle kunna skaffa nya insikter och valideringen av simulatorstudier.

Nyckelord:
distraktion, ögonrörelser, åtgärd, fältstudie

ISSN:	Språk:	Antal sidor:
0347-6030	Engelska	58

Preface

This literature overview was produced mainly as a state-of-the-art report for the IVSS project Inattention and Drowsiness with Saab Automobile as the project leader. The goal of the project is to evaluate a distraction countermeasure that is supposed to direct the driver's visual attention back to the road when he or she has looked away from the centre forward for too long. The evaluation will be done in the field with a small-scale field operational test (FOT). This will be the first project in which an eye tracker will be used in the field for a longer period of time in order to determine glance direction.

The present report focuses on visual distraction. It is concerned with methods that have been used to assess visual distraction and associated findings. Special attention is directed at field studies, and a few large-scale field studies are described in more detail. Furthermore, different algorithms which have been used to assess distraction in real time with eye trackers are presented and discussed. Finally, both theory and experimental research around distraction mitigation strategies are taken up.

I would like to thank my colleagues in the Inattention and Drowsiness project for valuable discussions. Special thanks to Fredrich Claezon (Saab) and Albert Kircher (VTI) who always had a willing open ear for discussions.

Acknowledgement

I am very grateful to Arne Nåbo (Saab) and IVSS for initiating and sponsoring the project, which is a great opportunity to learn more about distraction and working in the field.

Linköping September 2007

Katja Kircher

Cover: Albert Kircher, VTI and photos.com

Quality review

Review seminar was carried out on 2007-06-15 where Professor Håkan Alm reviewed and commented on the report. Katja Kircher has made alterations to the final manuscript of the report. The research director of the project manager Lena Nilsson examined and approved the report for publication on 2007-09-21.

Kvalitetsgranskning

Granskningsseminarium genomfört 2007-06-15 där Håkan Alm var lektör. Katja Kircher har genomfört justeringar av slutligt rapportmanus 2007-06-21. Projektledarens närmaste chef Lena Nilsson har därefter granskat och godkänt publikationen för publicering 2007-09-21.

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by Katja Kircher
VTI (Swedish National Road and Traffic Research Institute)
SE-581 95 Linköping Sweden

Summary

Until recently there was no generally accepted definition of distraction, and the most prominent discordance was that some researchers included cognitive inattention in the concept, while others reserved the term solely for visual distraction. In 2005 a large part of the First International Conference on Distracted Driving was dedicated to agreeing on a definition. The resulting definition clearly excludes long-term impairments like fatigue and alcohol intoxication, and states that the attention must be drawn away from driving towards something else in order to qualify as ”distraction”.

A multitude of methods has been used to assess the prevalence and the types of driver distraction that occur, and to describe the consequences in terms of driving performance and crash involvement. There is strong agreement that distraction is detrimental for driving, and that the risk for crashes increases. Only recently the method of remote eye tracking has emerged, which enables real time identification of visual distraction. So far this method has mostly been used in driving simulators, and different algorithms that diagnose distracted drivers have been tested with promising results.

Earlier research has shown that eye glances away from the road rarely exceed a duration of 2 sec. Most ”normal” glances range from about 0.7 sec. to slightly above 1 sec. In general, drivers rather opt for repeated glances instead of extending one single glance, if the secondary task demands attention for a longer period of time. It has been shown, however, that repeated glances have more detrimental effects on driving performance than a single glance of the same duration as one of the repeated glances. Apparently the drivers look away from the forward roadway again before they are completely back “in the loop”. Consequently, most algorithms that diagnose driver distraction based on glance behaviour do not only consider the most recent glance, but take the recent glance history into account.

Some distraction mitigation strategies have been tested in driving simulators. The drivers were either advised to look back at the road, or the interaction with the secondary task was terminated by the system. The results of those studies were mixed, and it could not clearly be shown that the countermeasures tested improved driving performance. It has to be noted, however, that the results stem from driving simulator experiments, during which distraction was induced artificially. It is recommended to test both the algorithms used to diagnose driver distraction and the countermeasures in the field with naturalistic distraction.

Generally it is important to focus research on naturalistic distraction because it is not clear how much artificially induced distraction makes the driver ”forget about” driving, or whether it rather resembles dual task performance in which the driver tries to maximise performance in both tasks and is well aware of the additional demands. A field study with real time eye tracking would be able to shed light on this question and also allow to evaluate a possible distraction countermeasure over a prolonged period of time.

Förardistraktion – En litteraturstudie

av Katja Kircher
VTI
581 95 Linköping

Sammanfattning

Fram till nyligen fanns ingen allmänt accepterad definition av distraktion och den största oenigheten låg i att några forskare inkluderade kognitiv ouppmärksamhet i konceptet, medan andra använde begreppet enbart för visuell distraktion. Under 2005 ägnades en stor del av den första internationella konferensen om distraherad bilkörning (First International Conference on Distracted Driving) åt att komma överens om en definition. Den resulterande definitionen utesluter klart och tydligt långvariga nedsättningar som trötthet och alkoholpåverkan samt kräver att uppmärksamheten måste dras bort från körningen och till något annat för att tillståndet ska kallas för ”distraktion”.

En mångfald av metoder har använts för att skatta förekomsten av olika typer av förardistraktion samt för att beskriva konsekvenserna när det gäller körbeteende och olycksrisk. Det finns stor enighet i att distraktion har negativa effekter på körbeteendet och att olycksrisken ökar. Under den senaste tiden har metoden att mäta blickriktning på distans börjat användas mer och mer, vilket möjliggör identifikation av visuell distraktion i realtid. Hittills har denna metod mest använts i körsimulatorer och olika algoritmer som diagnostiserar förardistraktion har testats med framgång.

Tidigare forskning har visat att blickar bort från vägen sällan tar längre tid än 2 sekunder. De flesta normala blickar åt annat håll har en längd mellan 0,7 sekunder upp till en dryg sekund. Förarna väljer snarare att titta bort flera gånger istället för att titta bort en gång under längre tid om sekundäruppgiften kräver en längre stunds uppmärksamhet. Man har dock kommit fram till att upprepade blickar bort från vägen försämrar körprestationen mer än en enda blick av samma längd som en av de upprepade blickarna. Tydligen tittar förarna bort från vägen igen innan de är helt tillbaka ”i loopen”. De flesta algoritmer som diagnostiserar förardistraktion baserat på blickbeteendet tar därför inte bara hänsyn till den senaste blicken bort, utan betraktar även blickbeteendet under de föregående sekunderna.

Några distraktionsvarningssystem har testats i körsimulatorer. Förarna har då antingen fått rådet att titta tillbaka på vägen eller så har förarens interaktion med sekundäruppgiften brutits. Resultaten av dessa studier har varit blandade och det har inte funnits några tydliga indikatorer på att körbeteendet skulle ha förbättrats med de distraktionsvarningssystem som testats. Det är viktigt att komma ihåg att resultaten härstammar från experiment som gjorts i körsimulatorer där förarna distraherats artificiellt. Forskarna rekommenderar att testa både algoritmerna som diagnostiserar förardistraktion och distraktionsvarningssystemen i fält där naturlig distraktion förekommer.

Det är viktigt att forskningen fokuserar på naturlig distraktion, eftersom det inte är klart huruvida artificiellt framkallad distraktion låter föraren ”glömma” bilkörningen eller om det snarare blir en ”kombinationsuppgift” där föraren försöker maximera prestationen i båda uppgifterna och är mycket medveten om den förhöjda belastningen. En fältstudie med blickriktningsmätning i realtid skulle kunna belysa denna frågeställning och samtidigt möjliggöra en bedömning av en distraktionsvarning över en längre tidsperiod.

1 Introduction

In recent years the interest in distracted driving has grown, even though some researchers started classifying different distractors and their frequency in accident involvement much earlier. Now the media, governments and the public become more and more aware of the problem, especially with the advance of mobile phone use while driving. Wierwille and Tijerina (1998) showed that a relationship exists between the visual demand of in-vehicle systems and accident occurrence, which indicates that systems that are meant to help the driver can also be hazardous, not to mention systems that only have entertainment qualities but do not support the driver with the driving task. Much of the current literature focuses on distraction by in-vehicle information systems (IVIS) or advanced driver assistance systems (ADAS) or so-called “nomad systems”, which include cell phones, laptops and external GPS systems, in other words systems that are not integrated in the car network. Distraction can, however, also come from all kinds of other sources, like passengers, animals or occurrences outside the vehicle.

This report was written with the goal of collecting knowledge on existing research for a project that is concerned with developing and evaluating a distraction countermeasure. The activation of the countermeasure is based on glance behaviour. Two instrumented vehicles, one truck and one passenger car, are driven by eight participants each. Every driver uses the vehicle during one month. During the first ten baseline days no distraction warnings are presented. Then the distraction countermeasure is switched on and the driver receives warnings when the distraction criterion is reached. The main objective of this report with respect to the project was to gather knowledge on visual distraction, which was then used as a basis for building the distraction warning algorithm.

In the first part of the present literature review different definitions of driver distraction are discussed. In the second part different methods for measuring driver distraction are presented and their advantages and disadvantages are considered. Some studies using different methods to investigate questions related to distraction are presented. Special focus lies on studies that measure eye glance behaviour. The influence of looking away from the road on performance measures like speed, lane-keeping and other behavioural variables is examined. Finally a few larger-scale field studies that were at least partially concerned with distraction are discussed, because the method of choice for evaluating the distraction countermeasure mentioned above can be considered a field operational test, albeit small scale in terms of the number of research vehicles. The final chapter deals with the concept of distraction as opposed to secondary task performance.

2 Definition of Distraction

Until recently there was no generally accepted definition for driver distraction. Due to the lack of a common definition, many researchers came up with their own definition or remained vague, which can render it difficult to compare research results directly. Only recently a group of internationally renowned scientists attempted to promote a common definition for driver distraction.

2.1 First International Conference on Distracted Driving

A conference on “Distracted Driving” was held in Toronto in October 2005. Much of the event was devoted to agreeing on a good definition. The following statements are excerpts from the home page of the conference (http://www.distracteddriving.ca/english/index.cfm?url.language=english).

Tasca’s (2005) paper is centered around defining distraction. He first presents different definitions found in the literature, based on which he develops his own definition. He first quotes a definition by Ranney, Garrott and Goodman (2001):

- Driver distraction may be characterised as any activity that takes a driver’s attention away from the task of driving.
- Any distraction from rolling down a window, over adjusting a mirror, tuning a radio to using a cell phone can contribute to a crash.
- Four distinct categories of distraction exist (but more than one can be active at one time):
    - Visual (e.g. looking away from roadway)
    - Auditory (e.g. responding to ringing cell phone)
    - Biomechanical (e.g. adjusting CD player)
    - Cognitive (e.g. lost in thought).

Ranney et al. (2001) specifically include being “lost in thought”. Being “lost in thought” is a phenomenon where the driver directs his attention away from the driving task to his own internal thoughts without being distracted by something external. Here this type of distraction is named ”cognitive distraction”, which could be considered somewhat misleading, as it implies that the other types of distraction presented here are not cognitive. It seems safe to assume that distraction always involves ”cognitive distraction”, otherwise it would be an additional activity, a ”secondary task”, performed by the driver while she still consciously tries to attend to the driving task (though possibly with degraded results).

Stutts, Reinfurt, Staplin and Rodgman (2001) as well as Stutts et al. (2003) state that distraction occurs when a driver is delayed in recognition of information needed to safely accomplish the driving task because some event, activity, object or person (both inside and outside the vehicle) compelled or tended to induce the driver’s shifting attention away from the driving task (citing Treat, 1980, p. 21). The presence of a triggering event distinguishes a distracted driver from one who is simply inattentive or “lost in thought”. Thus, these authors explicitly exclude the state of being “lost in thought” from their definition of distraction.

Also Beirness, Simpson and Desmond (2002) see the need to distinguish inattention from distraction. They formulate the following requirements for distraction:

- Need to distinguish distraction from inattention
- Distracted driving is part of the broader category of driver inattention
- Presence of a triggering event or activity distinguishes driver distraction as a subcategory of driver inattention.

Green (2004) states that “driver distraction” is not a scientifically defined concept in the human factors literature. According to him, with driver distraction a layperson means that something is drawing the driver’s attention to a different object, direction or task, which is not concerned with the primary driving task. This means that a distractor grabs and retains the driver’s attention. This statement includes the fact that the attention ”is pulled away” instead of being redirected voluntarily. Therefore secondary tasks, which are performed while the driver consciously tries to distribute his attention between the driving task and the secondary task should be excluded.

After having reviewed the literature review Tasca (2005) proposes his own definition of driver distraction and states that distraction occurs when there is:

- A voluntary or involuntary diversion of attention from primary driving tasks not related to impairment (from alcohol/drugs, fatigue or a medical condition).
- Diversion occurs because the driver is:
  - performing an additional task (or tasks) or
  - temporarily focusing on an object, event or person not related to primary driving tasks.
- Diversion reduces a driver’s situational awareness, decision-making and/or performance resulting in any of the following outcomes.
  - collision
  - near-miss
  - corrective action by the driver and/or another road user.

Thus, Tasca does not exclude voluntary secondary task executions, but the category ”lost in thought” seems to be excluded, even though this is not completely clear. Tasca apparently only considers the diversion of attention to be a distraction when the diversion results either in a collision, a near-miss or a corrective action by the driver or another road user. This means that the driver who by chance did not cause any evasive actions or worse, even though his attention lay elsewhere, would not be classified as having been distracted.

Smiley (2005) describes distraction as “misallocated attention”. She states that it depends on the driver state, the driving task and the driving environment to which extent attention is misallocated. Just as Tasca, she claims that the major reason for distraction to occur at all is that humans are “serial, limited capacity processors of information”, who at times do not prioritise well. She promotes visual search, vehicle control and conflicts and crashes as measures for distraction. Smiley advocates a broader definition of distraction, including the concept of being “lost in thought”, and including self-initiated secondary tasks. She also includes driving tasks, like looking in the mirror, that are executed in an inappropriate moment.

At the conference on distracted driving a point was made that in many instances a distracted driver does not have both hands on the steering wheel. It is recommended, however, that a driver should always have both hands on the steering wheel, in a safe position, except when operating another essential vehicle control. This point was not stated so clearly in other literature, though. A reason for this might be that much research on distraction involved the drivers’ taking their hand off the wheel, because they were instructed to operate in-vehicle controls. Therefore, if it is not motivated by instruction, taking one’s hand off the steering wheel can be useful as supplementary indicator for distraction.

Another point was that distractions often do not occur in isolation but that more than one “bad habit or technique” are executed simultaneously. In those instances the driving task is likely to be neglected even more.

Hedlund (2005), who summarised the conference, found it essential for distraction that the attention be directed away from driving to something else, which is not internal to the driver but something external (either in the car or outside). Hedlund also included the consequences of distraction in his definition. The consequences are not necessarily an observable manoeuvre, but an increase in risk for untoward situations. He presented the following criteria for distracted driving (slide 3).

- diversion of attention from driving
- because the driver is temporarily focusing on non-driving object, task, event, or person
- which reduces awareness, decision-making, or performance
- leading to increased risk of crashes, near-crashes, or corrective action.

In April 2006 the summary and recommendations of the conference were published, and the following definition of distraction was suggested (Hedlund, Simpson, & Mayhew, 2006, p. 2):

> *Distraction involves a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task, or event not related to driving, which reduces the driver’s awareness, decision-making, and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes.*

As clarification the following implications of the definition are listed (ibid.):

- Distractions exclude pre-existing conditions, including impairment by alcohol or drugs, fatigue, and psychological state; however, any of these can potentially make it easier for a driver to be distracted or can change the effect of a distraction.

- Distractions may be affected by personal characteristics such as age and medical conditions.
- Distractions may be affected by driving conditions and situations.
- Distractions need not produce immediate consequences such as corrective actions or crashes, but do increase the risk of these consequences.

The conference delegates agreed that this definition provided a sound basis for future research, even though it was deemed necessary to formulate simpler definitions for certain audiences.

2.2 Other Literature

Other recent literature has been reviewed in order to find more general and operational definitions used in studies of distraction.

Tijerina (2000) differentiates between three types of driver distraction that are relevant for traffic safety: general withdrawal of attention, selective withdrawal of attention and biomechanical interference. The first occurs when the drivers look away from the road. It depends on how long and how frequently the driver looks away from the road whether this type of distraction becomes dangerous or not. Further down the relationship between glances away from the road and safety is described in more detail. The second type of driver distraction, selective withdrawal of attention, is what other authors describe as “cognitive inattention”. It is described as the result of increased cognitive workload and does not involve the driver’s looking away from the road. Tijerina claims that in this state lane keeping and speed maintenance are not affected, but object and event detection can be degraded (see e.g. Haigney & Westerman, 2001). Both visual and cognitive withdrawal of attention lead to a narrowed fuctional field of view and more open-loop instead of closed-loop scanning behaviour (see Jahn, Oehme, Krems, & Gelau, 2005 for further references). The third type of driver distraction, the biomechanical interference, occurs when the driver moves his body out of the neutral position or takes the hands off the steering wheel. This can delay or hinder the optimal execution of manoeuvres.

Streff and Spradlin (2000) provide a review of some literature on distracted driving. They give the following definition of distraction: ”Distraction in the driving situation can be defined as a shift of attention away from stimuli critical to safe driving toward stimuli that are not related to safe driving” (p. 4). They continue defining ”attention” as: ”Attention is generally defined as the process of concentrating or focusing limited cognitive resources to facilitate perception or mental activity” (ibid.). This definition does not clearly state whether internal thoughts are included or not. The authors focus first on theories on attention and consider ”selective attention”, ”divided attention” and ”sustained attention”. They state that crashes become more likely as drivers purposely attend to stimuli not related to driving safely (selective attention), that they divide their attention between too many stimuli, or that they are being distracted (here described as when attention is focused on something irrelevant to driving unintentionally).

Young, Regan and Hammer (2003) published a literature review on studies concerned with distraction caused by activities or objects inside the vehicle rather than outside the vehicle. They make a distinction between “technology based distraction” and “non-technology based distraction”. The authors say that “driver distraction forms part of the broader category of driver inattention" (p. 2). They then quote Treat (1980) whose definition is used by the American Automobile Association Foundation for Traffic Safety (see p. 10). Much of the literature presented in the review examines one or several devices or activities and their influence on driving behaviour. Thus, the assumption seems to be that carrying out activities that are not directly related to the driving task can be subsumed under "distracting activities". In the report different measures for distraction and their advantages and disadvantages are discussed.

Harbluk, Noy and Eizenman (2002) do not give a definition, but use what they call ”cognitive distraction”. In their study they specifically wanted drivers to watch the road, but to think about something else. Distraction was assumed to occur when the drivers were computing numbers in the head. They focussed therefore, unlike many other authors, specifically on the ”lost in thought” phenomenon, which other authors sort under ”inattention” but not ”distraction”.

Almén (2003) does not give a definition of distraction, but essentially works with the criterion of looking away from the road a certain period of time. She does not record, though, whether her participants really look away from the road, but gives them a secondary task (reading numbers from a display on the passenger's seat). Two seconds after the onset of the secondary task a warning signal for distracted driving comes. Therefore her operational definition of distraction is that the participants have had a distractor for at least two seconds.

Karlsson (2005, p. 6 f.) uses the following working definition: ”Distraction occurs when a driver is delayed in the recognition of information needed to accurately bound the field of safe travel and the minimum stopping zone because an event (a distractor) external to the driver compelled or tended to induce the driver's shifting attention away from this information." He refers to the ”field of safe travel" postulated by Gibson and Crooks (1938) and otherwise uses the definition of Treat (1980) as a basis for his definition.

Brown (2005) did not attempt to distract her participants at all but used occlusion goggles instead, which were shut when the driver arrived at a certain location, such that the driver could not see anything any more. The goggles were shut for not more than two seconds. This was meant to simulate driver distraction. No information is given as to whether the participants rated this method as simulating distraction well. Occlusion as a means of investigating distraction is discussed further below.

Victor (2005, p. 68) defines distraction slightly differently, including the quality of the driving behaviour in the definition: ”*Distraction* is defined as attention, measured as eye movements, being captured by information that is irrelevant to the driving situation to the degree that a) insufficient attention is left for the primary control task of driving, *and/or* b) that driving performance (e.g. lane keeping or speed control) is compromised" (italics in original). By including driving behaviour a criterion is needed as to when one can speak of compromised performance. This can be different in different environments. It seems inadequate to assume distraction as soon as degraded driving behaviour is noted, which is indicated by the ”*or*" phrase in the definition, because degraded behaviour can result from many other sources like fatigue, intoxication, inability, etc., which should not be subsumed under distraction.

3 Methods and Findings Concerned with Distracted Driving

In this section findings related to distracted driving are presented. The methodologies with which the effects of distracted driving were assessed vary widely. They range from driving simulator studies over test-track to field studies, and they make use of different methods and measures. Questionnaires, polls and accident analyses are also used. In connection with the results of different studies the advantages and disadvantages of each method will be discussed. Of course the advantages and disadvantages of each method have to be regarded with respect to the goal of the study and cannot necessarily be taken as absolute (Kantowitz, 1992).

3.1 Laboratory Studies/Driving Simulator Studies

Laboratory studies are conducted in a mock-up environment, which, in the case of distracted driving, almost always consists of a driving simulator. The simulator can be a simple computer monitor with a chair in front of it, up to a high fidelity moving base simulator with a real car body included.

The advantages of a simulator study are that the environment can be controlled, such that the situations desired by the experimenters can be presented, and that all participants can be subjected to the same situations. A large number of different situations like different road conditions, illuminations and weather conditions can be studied without having to wait for them to occur in a natural environment. Dangerous situations can be studied, which would not be possible on the road, due to ethical reasons. Results obtained in a high fidelity simulator are often found to be valid for at least certain aspects of real world driving, and usually validation studies exist for those simulators (e.g. Reed & Green, 1999; Törnros, 1998; Törnros, Harms, & Alm, 1997). A further advantage of a driving simulator is that prototypes of warning systems often are easier to build for a simulator than for a real vehicle. Often more precise log data and a larger number of log variables are available.

The disadvantages of a simulator study depend on the quality of the simulator. The less advanced the simulator is, the cheaper to use it usually is, but on the other hand external validity is lost. A more advanced simulator can be very expensive. Participants are obviously aware of the fact that they are being observed, which might lead to a non-natural behaviour. The available time for research in a simulator is usually restricted, therefore it is not clear whether only the novelty effect of a certain measure or device is investigated, or whether the same behaviour would be observed in a long-term study. Also, the number of participants in a simulator experiment is rather limited, therefore it is important to choose representative participants. Especially in relation to distraction simulator studies have drawbacks, which might not be important when investigating other issues. It is difficult to induce distraction, because this is in a sense a contradiction in terms. As time is limited and the participants probably are aware of the test situation and often want to perform well, it is not easy to collect many incidents of "true distraction" within a driving simulator experiment. Therefore secondary tasks are presented to the participants to work as "distractors". It is not clear, however, whether the behaviour resulting from this corresponds to the behaviour found in "true distraction", that is, whether there is a difference between "secondary task performance" and "performance while distracted". For further discussions of the advantages and disadvantages of driving simulators as research tools see Goodman et al. (1997) and Reed and Green (1999).

The literature on simulator studies in connection with some form of distraction is extensive. There has been a lot of research of the distracting effects of cellular telephone use while driving (see Kircher et al., 2004, for further references), of how navigation systems distract the driver (see Tsimhoni, Smith, & Green, 2004, for further references), and so on. Not so many studies were concerned with distraction countermeasures per se, though, where the main point was to induce distraction, to see how to counteract it best.

Almén (2003) conducted one study in a high fidelity driving simulator, in which the distractor consisted of a reading task. The participants had to verbally report numbers that were presented on a computer on the passenger seat. A countermeasure was tested, but no convincing effects were found. One conclusion of the study was that it was not easy to induce distraction artificially.

Karlsson (2005) came to a similar conclusion after two simulator studies during which a detection task that was based on a matrix of arrows was used as distractor. This distractor had been developed in the HASTE project (Jamson & Merat, 2005) and is called S-IVIS (surrogate in-vehicle information system). In both of Karlsson's studies the distractor was "announced" by an auditory signal, to which the participant had to react by performing a visual secondary task. It was found, though, that the participants were well aware of the fact that they took their eyes off the road, so the resulting behaviour was that they tried to fulfil the secondary task but still monitored the traffic as much as they could.

Donmez et al. (2007), however, report an experiment in a simulator in which drivers were distracted by a task that involved matching a character string memorised earlier to what was read on a display. The participants were paid according to their performance on the secondary task. Distraction mitigation strategies were visual two-stage warnings that were given when 2 seconds (first stage) respectively 2.5 seconds (second stage) of off-road glance duration were exceeded according to an algorithm, that took into account both the current off-road glance duration and a 3 seconds moving average of the accumulated off-road glance duration. The warnings given were either coloured stripes appearing on the display where the secondary task was presented, or LEDs that were lit on the dashboard. SeeingMachine's product FaceLab was used for real time gaze direction assessment. The authors found their setup to work well, and they do not report any difficulties with experimenter-induced distraction in the simulator.

Zhang, Smith and Witt (2006) conducted an experiment with a relatively similar setup as the one of Donmez et al. (2007), except that they did not warn the drivers when they were distracted but only observed changes in behaviour. Even though effects in driving behaviour could be found that were related to the induced distraction, the authors recommened validation in the field where natural distraction occurs.

3.2 Test Track Studies

A step further towards reality are test track studies, which are performed on a closed course, but while driving a real car. The conditions are more controlled than in a field study. The investigated situations can be more dangerous than in field studies, because surrounding traffic is either absent or controlled.

Similar to simulator studies, though, the participants are usually quite aware of the experimental setting and of being observed, it is not easily possible to perform long-term studies, and the number of participants is approximately as limited as for simulator studies. Even though they might be less expensive than studies in high fidelity driving simulators, test track studies are still rather costly.

One study, which examined individual differences with respect to distraction in relation to lane exceedences, was performed on a test track (Tijerina, Parmer, & Goodman, 1999). Drivers were distracted from the driving task with a navigation system, on which they had to perform certain tasks. The participants' performance on a number of temporal visual perception and cognitive tasks was correlated to driving performance on the test track. It turned out that there were low but consistent correlations between the performance on the track and on the test battery.

Shutko (1999) performed a test track study, in which the participants, who were commercial drivers, drove a truck and had to perform a route selection task on an in-vehicle display as distractor. At a certain point empty plastic barrels were released and rolled out in front of the truck. Different collision avoidance warnings were tested.

Again, just as for the simulator studies, it is not the aim to wait until the participants get distracted "naturally", therefore they are distracted artificially. The question of external validity with respect to distraction arises again. For many purposes these approaches still are reasonable. However, if the object of interest is a distraction countermeasure it is of paramount importance to be sure that the driver is distracted naturally.

3.3 Field Studies

A field study is the method that is closest to real driving, and it therefore has high external validity. The possibility to control the environment is relatively limited, and participants cannot deliberately be exposed to dangerous situations. There are many possible variations of field studies, some of which are described below.

Time frame:	The studies can be short, lasting only for a single drive, as has been the case for most field studies up to now, but a more extreme field study, the 100-car study, which is described in more detail below, lasted for more than one year (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005). Therefore, in principle, field studies make it possible to investigate long term effects of certain measures under natural conditions. At the Virginia Tech Transportation Institute (VTTI) further large-scale field studies are underway and in planning. While VTTI focuses on observing driving behaviour without intervening measures, it is also possible to study "before and after" effects in the field. To this end especially the University of Michigan Transport Research Institute (UMTRI) conducted several field operational tests (FOTs) where the participants received an instrumented vehicle for between two and six weeks. Typically the participants use the vehicle first with deactivated driver support system, which is switched on after a certain time period. Currently a large FOT called Integrated Vehicle-Based Safety Systems (IVBSS) involving both passenger cars and trucks with the goal to evaluate an integration of several collision avoidance warning systems is in preparation (Sayer, 2006).

Informed participants: Field studies can be conducted with recruited participants that usually drive instrumented vehicles. In this case approximately the same restrictions with respect to number of participants apply as for the simulator and test track studies. Again, the 100-car study is a notable exception with 109 recruited drivers. In this study 80% of the participants drove their own cars which had been instrumented. The ACAS FOT in Michigan had almost 100 participants (Sayer, Mefford, Shirkey, & Lantz, 2005). Each participant received one of eleven similar cars and drove it for four weeks.

Other types of field studies are performed without the participants' being informed, for this kind of study the collected data are usually relatively limited and focus on macro-level data (e.g. Vogel, 2002). Typically speed measurements or headway measurements are collected. This latter type of field study is not suitable for research on distracted driving.

Experimenter: Field studies can be conducted with or without an experimenter in the car. Having an experimenter in the car increases the participants' awareness of being studied, but is often necessary for instructions, operating equipment, data collection, and for safety reasons. In some field studies the experimenter also acts as observer and logs the participants' behaviour. Long-term studies are usually conducted without an experimenter in the car, but the cars tend to be equipped with multiple data logging systems that ideally should be hidden from the participants' and the other road users' view.

Naturalistic/FOT: In recent years with a growing number of larger-scale field studies being conducted and planned a discussion has come up regarding the nomenclature of the different types of studies. It was suggested to view these types of tests as lying somewhere on a continuum from completely naturalistic to more experimental in design. In the former approach the participants ideally drive their own vehicles without any further instructions, and the data collection process should be as discreet as possible in order to avoid changes in behaviour due to being observed. The goal is to study driving behaviour as it is. In the case of the 100-car study one goal was to collect naturalistic pre-crash data. A FOT on the other hand involves a baseline data collection phase where the participants drive without special instructions, and a "treatment phase", involving for example an ITS device in the car or some kind of special instruction to the driver. Here the goal is to examine the effects of the treatment on driving behaviour in a within-subjects design.

Harbluk, Noy and Eizenman (2002) examined so-called "internal distraction" in real traffic by letting their participants compute numbers in the head (via a handsfree telephone). They found narrowed scanning behaviour and reduced scanning of instruments and mirrors with increasing cognitive workload in their participants. A good review of further studies that examine the effects of talking on the phone and of using navigation systems is provided by Young, Regan and Hammer (2003).

Many studies investigating the effects of the use of navigation systems and cellular telephones as well as other IVIS implicitly study driver distraction, but the distraction was always induced by the experimenter in some way or another, and is not “natural”. The exceptions in which natural distraction was observed, were the 100-car study conducted around Washington DC in the United States (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005), the ACAS FOT study, conducted in Michigan in the United States (Sayer, Mefford, Shirkey, & Lantz, 2005) and the RDCW FOT also conducted in Michigan (Sayer, Devonshire, & Flannagan, 2005). Even though those studies did not specifically focus on distraction, valuable insights into driver distraction and driving performance related to safety was gained. The three studies are described in more detail below.

3.3.1 The 100-car Naturalistic Driving Study

The National Highway Traffic Safety Administration (NHTSA) and the Virginia Department of Transportation (VDOT) in the USA commissioned the so-called 100-car naturalistic driving study, in order to collect naturalistic pre-crash data, and generally to collect a large amount of naturalistic driving data. The study was conducted by the Virginia Tech Transportation Institute (VTTI). The full report on the experimental design phase (Neale et al., 2002), an overview of the design and the results (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005), the full phase-II results report (Dingus et al., 2006), a report on the impact of inattention on crash risk (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006) and a report on the relative risk of potentially unsafe driving behaviour (Klauer, Sudweeks, Hickman, & Neale, 2006) are available. Around 80% of the participants drove their own cars (which had been instrumented for the study) during the period of one year, the others received leased vehicles. Altogether around 42300 hours of driving, that is, almost five continuous years of driving, were sampled. The collected data were speed, lateral and longitudinal acceleration, headway, presence of side obstacles, video recordings of five cameras (driver’s face and driver’s side of vehicle, passenger’s side of vehicle outside of car, forward view, rear view, over-the-shoulder view of the driver’s hands and surrounding area), GPS data and others. The cameras recorded at 30 Hz, the compression algorithm reduced the actual number of unique frames to around 7.5 frames/second. The drivers could press a button in order to flag incidents.

The selection of participants followed several practical reflections. In order to increase the probability for rear-end crashes young and male drivers should be overrepresented (though they were not, in the end). The desired average mileage was high (27,000 miles per year), and the selected research area was Washington DC urban area. Only drivers with prior crash involvement were considered, and they were preferred when they had occupations necessitating extensive urban driving.

In the study 82 crashes, of which 15 were police-reported, 761 near-crashes and 8,295 incidents were registered. For 13 of the crashes log data were incomplete, because the acquisition system was still in the start-up phase. It was stated that the drivers “soon” forgot about the instrumentation of the vehicles. It was speculated that one hour of driving time with the newly instrumented vehicle was enough in some cases, which was derived from the drivers’ engaging in dangerous behaviour, among other things. Of all drivers, 7.5% never experienced an event of any severity, but the same percentage was involved in many incidents and 3 or 4 crashes.

In order to find crashes, near-crashes and incidents in the data, trigger criteria for certain variables were determined with the goal to miss not more than 10% of such events while reaching a false-alarm rate of less than 30%. The falsely identified events were later discarded by the data reductionists. The final triggers are presented in Table 1. It turned out that due to the high variability in driving style more than 110,000 triggered events had to be viewed in order to identify real 9,125 events. It has to be noted that 965 of those events could be attributed to only two of altogether 109 primary and 132 additional drivers.

Apart from this event database, a baseline database was created, which was stratified according to vehicle involvement in events. Thus, a vehicle which was involved in three per cent of the crashes, near-crashes and incidents would provide three per cent of the baseline epochs. It has to be noted that four vehicles that were not involved in any incident were, thus, not represented in the baseline data at all. The baseline epochs were randomly selected film segments of six seconds duration during which the vehicles maintained a speed of at least 5 mph (ca. 8 km/h). Those epochs could be compared to the six seconds around an event (five seconds before until one second after) in order to determine the relative frequency of activities during events and during baseline driving. For 5,000 of the 20,000 baseline epochs video based eyeglance analyses were performed frame by frame.

Table 1 Event triggers used in the 100-car study, adapted from Klauer et al. (2006, p. 11).

Trigger type	Description
lateral acceleration	lateral motion ≥ .7 g
longitudinal acceleration	acceleration or deceleration ≥ .6 g acc. or dec. ≥ .5 g and forward TTC ≤ 4 s all longitudinal decelerations between .4 g and .5 g coupled with a forward TTC value of ≤ 4 s and that the corresponding forward range value at the minimum TTC is not greater than 100 ft
event button	activated by the driver
forward time to collision (instrumented vehicle and vehicle in front)	see longitudinal acceleration (only used in combination with longitudinal acc.)
rear time to collision (instrumented vehicle and vehicle behind)	any rear TTC trigger value ≤ 2 s that also has a corresponding rear range distance of ≤ 40 feet any rear TTC trigger value in which the absolute acceleration of the following vehicle ≥ .3 g
yaw rate	any value ≥ 4-degrees change in heading that is followed by another ≥ 4-degrees change in heading in the other direction with a 3-second window of time

Engagement in “secondary behaviour” was found in 73 per cent of the baseline epochs. It has to be noted, though, that drowsiness, unspecific eyeglances and so-called “driving related inattention”, which includes checking the mirrors and the speedometer, are included in this number. “Secondary task engagement”, that is, an action specifically decicated to something not driving related, was found in about 55 per cent of the baseline epochs either alone or in combination with one of the “secondary behaviour” categories mentioned before.

Based on the results of their analyses, Neale, Dingus, Klauer, Sudweeks and Goodman (2005, p. 6) postulate that “driver distraction has to be expanded to a more encompassing ‘driver inattention’ construct, that includes *secondary task engagement* and *fatigue* as well as two new categories, ‘*Driving-related inattention to the forward roadway*’ and ‘*non-specific eye glance*’” (italics in original). Driver-related inattention means, that the driver checks e.g. the mirrors or their blind spots, but fails to pay attention to the forward roadway, where something critical is happening. The non-specific eye glance category comprises of glances away from the road, but at no specific object. They are usually only momentary, but the data “suggested that driver’s glances away from the forward roadway potentially contribute to a much greater percentage of events than has been previously thought” (ibid., p. 7).

In the study 78 per cent of the crashes and 65 per cent of the near crashes were classified as having one of the four categories mentioned above as contributing factor. “Secondary task engagement” was the largest category, followed by “driving-related inattention”. These two categories were present during baseline driving with around the same percentages, however. An odds-ratio calculation revealed that moderate to severe drowsiness increased the likelihood for at-fault crashes and near-crashes more than sixfold, while the performance of complex and moderate secondary tasks increased the likelihood two- to threefold.

Analyses were performed to examine how “eyes off forward roadway” and near-crash/crash risk were related to each other. The variables that were studied are presented in Table 2.

Table 2 Eyes off forward roadway metrics as used in the 100-car study, adapted from Klauer et al. (2006, p. 100).

Eyes off forward roadway metric	operational definition
total time eyes off forward roadway	the number of seconds that the driver’s eyes were off the forward roadway during the 5 seconds prior and 1 second after the onset of the precipitating factor
number of glances away from the forward roadway	the number of glances away from the forward roadway during the 5 seconds prior and 1 second after the onset of the precipitating factor
length of longest glance away from the forward roadway	the length of the longest glance that was initiated during the 5 seconds prior and 1 second after the onset of the precipitating factor
location of longest glance away from the forward roadway	the location of the longest glance (as defined by length of longest glance) – location is based upon distance (in degrees) from centre forward and is in one of three categories: < 15°, between 15° and 30°, > 30°

It has to be noted that no clear definition of “off the forward roadway” could be found in the report, and that there are varying definitions of the time window used (5 s prior to 1 s after the onset of the incident versus the period of 6 s before the onset of the incident). Furthermore, the “location of longest glance away from the forward roadway” was subdivided in categories based on 15°-steps in the definition, whereas in the text 20°-steps were used (below 20° away from centre forward, between 20° and 40°, more than 40°). Generally no distribution parameters are given for the presented results.

For 40% of the crashes drivers did not look away from the forward roadway from 5 s prior to 1 s after the onset of the conflict. The accumulated average time of the drivers’ looking away from the forward roadway was around 1.8 s for crashes, around 1.25 s for near-crashes, around 1.05 s for incidents and around 0.85 s for baseline driving for the 6 s prior to the onset of the conflict. All differences were significant. Odds ratio calculations showed that the near-crash/crash risk more than doubled when the total time during which the driver’s eyes were off the forward roadway exceeded 2 s of 6 s.

The mean number of glances away from the forward roadway within the period of 5 s prior to 1 s after the onset of the conflict was slightly above 1.4 for crashes, around 1.3 for near-crashes and incidents, and around 1.1 for baseline driving. It is stated that the differences between near-crashes and baseline and between incidents and baseline were significant, but no clear statement is made for the difference between crashes and baseline.

The mean length of the longest glance away from the forward roadway lay above 1.6 s for crashes, slightly below 1.2 s for near-crashes, slightly below 1 s for incidents and slightly below 0.8 s for baseline driving. The differences were statistically significant for all pairs.

The results for the location of the longest glance show that for crashes and near-crashes the area between 20° and 40° is overrepresented. For incidents and baseline driving a larger percentage of the longest glances away from the forward roadway is directed at objects within 20° of centre forward, but also further away than 40° of centre forward. It has to be noted, however, that the duration of the longest glance was much shorter during baseline driving and for incidents as compared to crashes and near-crashes. This might allow the speculation that the longest glance for the latter two event types was not planned.

Especially with reference to rear-end crashes the authors suggest that distraction countermeasures could have large benefits (Neale, Dingus, Klauer, Sudweeks & Goodman, 2005, p. 7): "Of particular interest in the analyses of rear-end conflict contributing factors was the prevalence of distraction. An important aspect in rear-end crash countermeasure development is the degree to which an un-alerted driver can be warned and make a proper response." This statement is based on the fact that in 13 out of 14 crashes involving the instrumented vehicle and the vehicle in front *inattention to the forward roadway* was a contributing factor.

A canonical discriminant analysis was conducted on all 20,000 baseline epochs in order to find out whether driving performance indicators were able to discriminate between attentive and inattentive driving, that is, whether the driver is engaged in a secondary task or not. The variables used in the discriminant analysis can be found in Klauer et al. (2006) on page 112. It was found that the best predictors only accounted for less than one per cent of the variance associated with inattentive and attentive driving, and the analysis could not classify the epochs better than chance. The authors conclude that even though there are differences between inattentive and attentive driving those variables cannot explain them.

From the host of results obtained from the 100-car study the following are seen as especially relevant for the planned field operational test with a distraction warning system. It is shown that the visual behaviour of the driver is not only related to driving performance measures, but it is related to crash involvement. Crash risk increases when the driver looks away from the road for more than two seconds within a time span of six seconds. It is clearly stated that a distraction countermeasure could be beneficial for traffic safety. Furthermore, it was difficult to find patterns in the log files through which traffic incidents could be identified reliably. Additional video filming of the driving scene is therefore essential.

3.3.2 Field Operational Tests at UMTRI

The University of Michigan Transportation Research Institute (UMTRI) conducted several large-scale field operational tests (FOT). They involve typically around 50 to 100 lay drivers who are asked to use an instrumented car as they would use their own for about four to six weeks. Usually during the first quarter of the trial baseline data are sampled, that is, the cars function just like standard cars, apart from that they continuously collect data. When the baseline period is over a driver support system is activated automatically and remains on for the remainder of the study. Among the systems tested are adaptive cruise control and forward collision warning (ACAS-FOT described below) and road departure crash warning systems (RDCW-FOT described below). Even though field operational tests of this kind usually have the purpose to investigate the performance of the tested support system and possible changes in driving behaviour as reaction to system activation the large amounts of collected data also provide material for investigations of naturalistic driving behaviour. Below two of the field operational tests conducted at UMTRI are described in more detail, because reports concerned with driver distraction have been published based on the data collected during those studies.

ACAS-FOT

During the Automotive Collision Avoidance System Field Operational Test (ACAS FOT, the project was begun in June 1999 and completed in November 2004) 96 age-stratified, randomly chosen drivers in Southern Michigan used a prepared ACAS vehicle for four weeks. The vehicles were equipped with an adaptive cruise control system (ACC) and a forward collision warning system (FCW). The primary goal of the study was to investigate whether adaptive driver assistance systems would lead to increased driver distraction, operationalised by secondary activities of the driver. The secondary goal was to investigate how well drivers accepted a forward collision warning system and an adaptive cruise control system, when they had the chance to test it for a while under real conditions in the field.

For the first week the driver assistance systems were switched off, only conventional cruise control, which is a feature found in most North American cars, was available. The data of this week were used as baseline. After the first week the systems were switched on automatically and remained on for the remainder of the time.

Each driver's face was filmed by a camera pointing towards him or her, and the forward driving scene was filmed, too (1 Hz). For each driver clips of four seconds were sampled every five minutes at 10 Hz.

During the 12 months of field trials 137,000 miles were covered. The average trip length was 12 miles, although many trips were shorter than one mile and some exceeded 100 miles. 75 percent of all travels occurred in well-lit conditions, while 25 percent occurred in the dark. The oldest age group travelled slightly longer (38% of the total mileage) than the other two age groups (each 31% of the total mileage). Half of the mileage was driven on freeways. It was found that there were large individual differences with regard to personal mileage and how the trips were distributed (type of road, time of day, etc.).

It was found through data analysis and interviewing the participants that the drivers had experimented with the systems to test their functionality. Even though they had been asked to limit experimenting to the first few days with the system, there were instances when the system functionality was tested or demonstrated later on, too, especially when new passengers were in the car. In general, experimenting behaviour seemed to have subsided by the third week of system availability.

Sayer, Mefford, Shirkey and Lantz (2005) examined a random sample of 5% of the four second 10-Hz-clips for 66 drivers, stratified by week. Only clips in which the speed lay above 25 mph (40 km/h) were included. The goal was to establish whether the prevalence of secondary behaviour, that is, behaviour not related to the driving task, increased with the presence of adaptive driver assistance systems or not. To this end the selected 890 clips were coded by trained research assistants into containing no secondary behaviour or containing such behaviour, and which kind. The general result both for the introduction of FCW and ACC was, that the only increase in secondary behaviour could be found for “conversation with passenger”. This was interpreted such that the drivers were excited to tell their passengers about the new system.

In total almost 20% of the analysed video clips included secondary behaviour. As the duration of the secondary behaviour was neither taken account here nor in the 100-car study it is reasonable to multiply the value obtained here with 1.5 for comparison with the 100-car study, because the reviewed ACAS-FOT clips had a duration of 4 s while the 100-car epochs had a duration of 6 s. The adjusted ACAS-FOT value of almost 30% still lies substantially under the 55% of secondary task engagement during baseline driving in the 100-car study. One possible explanation might be the fact that the analysis in ACAS-FOT excluded video clips at speeds below 40 km/h. It is thinkable that drivers engage more in secondary tasks while travelling at low speeds, but the liability to engage in secondary tasks was not broken down into different speeds in any of the studies.

A full description of the study can be found in Ervin et al. (2005a; 2005b).

RDCW-FOT

During the Road Departure Crash Warning Field Operational Test (RDCW-FOT) 78 lay drivers produced 133,290 km naturalistic driving data. More than 500 variables were sampled at either 10 or 20 Hertz. The study is described in detail in LeBlanc et al. (2006a; 2006b). A report with the purpose to examine the effects of secondary tasks on naturalistic driving performance was published (Sayer, Devonshire, & Flannagan, 2005). For a stratified subset of altogether 36 drivers 1,440 video clips of five seconds duration were analysed (10 clips in each of 4 weeks for each of the 36 selected drivers). The minimum speed criterion was the same as for the ACAS FOT (> 40 km/h). It was ensured that the clips did not include situations in which the drivers received lateral drift or curve speed warnings. In the RDCW study secondary task engagement was found during 34% of the clips. The most frequently observed behaviour was “conversation with passenger” (15%), followed by “grooming” (6.5%) and “hand-held cell phone use” (5.3%). Not many of the clips stemmed from local roads and ramps, most likely due to the speed restriction. There seems to be a tendency, however, that drivers engage slightly more often in secondary tasks on “slower roads” than on limited access roads, which might support the notion that slower speeds are a contributing factor to secondary task engagement.

Manual glance analyses were made based on the 5-second video clips. During 61% of the clips at least one glance away from the forward scene could be observed, which lasted for .73 s on average. In 37% of the clips a second glance was observed which lasted for .79 s on average. The percentage and duration of the first and second glance away from the road were broken down into different secondary tasks, including “no secondary task performance”. Of all those categories “using a cell phone” resulted in the fewest glances away from the forward scene (54% of all clips for the first glance) and the shortest glances on average (.55 s). The highest percentage of clips with glances away from the forward scene was found for eating and drinking. The longest average glance duration was found for the category that included all other activities that did not belong to either conversation, grooming, cell phone use, eating/drinking or multiple activities and amounted to .87 s. Grooming followed with an average glance duration of .82 s The differences between the glance durations for first glances were not significant, however.

The effect of secondary task engagement on driving performance parameters was investigated, too. It was found that secondary task engagement led to significantly increased steering angle variance in comparison to driving without performing a secondary task. Phone use while driving was associated with the highest steering angle variance, even though the glances away from the forward scene were shorter than for any other category. No easily interpretable results were found for the effect of secondary task engagement on the standard deviation of lateral position (SDLP) and on mean throttle position and variance. Telephone use sticks out again when looking at speed control. Especially in clips during which the brake was engaged the mean speed variance was lower than for all other secondary task categories, including "no secondary task". Also when the driver did not brake, speed variance was relatively low during phone use as compared to the other categories.

The UMTRI-studies demonstrate, just as the 100-car-study, that secondary task engagement is frequent during driving. Valuable insights about natural glance behaviour are obtained. Again, however, it can be seen that manual glance analysis is very cumbersome and time consuming. Therefore advance of remote eye trackers is promising for this type of research.

3.4 Visual Occlusion as Distraction Research Method in Simulator and Field

Visual occlusion is a method that has been used in driver distraction research in many different ways. Visual occlusion is defined as "the physical obscuration of vision for a fixed period of time" (Gelau & Krems, 2004, p. 185). The theory behind the technique is that driving is a task with high visual demands (Sivak, 1996). Visual occlusion is considered to be a method with which it is possible to assess both the visual demands of driving and the visual demands of in-vehicle displays and the like. Furthermore, it is used to simulate distraction, and different occlusion intervals are used in order to assess whether a task can be interrupted without detrimental effects or not. The two parameters that can be manipulated are the *presentation* or *inspection time*, that is, the time during which the relevant information is visible, and the *occlusion time*, which is the time during which vision is obscured. It is possible to let the participants control for how long they want to view their task in order to determine task demands and possible intraindividual differences. Another possibility is to set the intervals at fixed values and observe changes in behaviour and performance decrements. Depending on the setting, the participant can either receive a secondary task during the occlusion periods or have one's vision completely obscured.

Different methods have been used to occlude the driver's view. One of the first devices were mechanical shutters attached to a baseball helmet. More modern devices prevent issues like re-accomodation concerns and light intensity problems by using a polarising filter during occlusion, which can be switched on very rapidly, and which does not change light intensity substantially. Other methods would be an interruption in the presentation of a simulated driving scene or of a display presented on a monitor.

Historically the first ones to use the occlusion technique to study drivers' visual behaviour were Senders, Kristofferson, Levison, Dietrich and Ward (1967). They found that longer occlusion periods lead to lower maximum speeds, and that curve negotiating places additional visual demands on the driver, but the studies have received some criticism on methodological grounds (Lansdown, Burns, & Parkes, 2004). The participant numbers were limited, and conclusions were drawn based on experimenter's judgement instead of on objective data.

Lansdown, Burns and Parkes (2004) discuss the validity of the occlusion technique in order to assess driver distraction and the suitability of in-vehicle information systems (IVIS). They see some promise in the technique but state that an empirical basis for it is still lacking.

A study in which the occlusion technique was used to simulate the demands of road traffic is reported by Baumann, Keinath, Krems and Bengler (2004). The inspection time of a navigation system interface was 1.5 s, and the occlusion time was 3 s. Addresses had to be entered in a navigation system while the car was parked. Performance was compared to conditions without occlusion both in a parked car and while driving. Task completion was longest and the error rate was highest for the driving condition, followed by the occlusion condition. Best results were obtained for the parked condition without occlusion.

Tsimhoni (2003) reports a simulator study in which forced occlusion of the task was used. The participants had to plan a route on an electronic map according to predetermined rules while the car was parked, while driving on a straight road, while driving on a road with moderate curves and on a road with sharp curves. Different occlusion and inspection time combinations were used. Total glance time was not found to be affected by road curvature, but total task time increased significantly from the parked condition over the straight road driving to the curvy and very curvy conditions. The participants rated the task to be more difficult with increasing occlusion time and with decreasing viewing time.

Van der Horst (2004) describes the research done at TNO with the specially developed PLATO spectacles (PLATO: Portable Liquid-crystal Apparatus for Tachistoscopic Occlusion). Godthelp, Milgram and Blaauw (1984) let the drivers choose how often they wanted to view the driving scene. This was done by having the drivers press a micro-switch, which opened the glasses for a period of .5 s. The visual behaviour was set in relation to “time to line crossing” (TLC). With increasing speed, occlusion time and TLC at the time when the glasses were opened again decreased (average occlusion time at 20 km/h: almost 6 s; average occlusion time at 120 km/h: slightly above 2 s).

Hoedemaker and Kopf (2001) used a technique with which only central vision was blocked, but peripheral vision was accessible, in order to evaluate effects of adaptive cruise control on different behavioural aspects. Several studies were conducted with the objective to prevent the driver from judging speed by means of visual flow. Stroboscopic occlusion was one approach to achieve this goal (van der Horst, 2004). Van der Horst comes to the conclusion that visual occlusion techniques are useful tools for investigating visual sampling behaviour and workload in driving. According to him they are also a useful means to assess safety effects of in-vehicle devices.

Noy, Lemoine, Klachan and Burns (2004) conducted a study with the goal to determine whether easily interruptable tasks were less distracting during driving than tasks that are difficult to interrupt. The authors compared visual occlusion in a static situation with driving in a simulator without visual occlusion. In the first condition the viewing time was 1.5 s and the occlusion time was 3 s. Participants had to perform different in-vehicles tasks. Subjective task demand differed between the tasks in the static condition, this effect was stronger when driving. More complex in-vehicle tasks suffered more from being interrupted by occlusion than simpler tasks.

Brown (2005) used the occlusion technique to simulate distraction. The participant drove around a closed course while vision was occluded for 2 s at random intervals. In one target situation vision was occluded while a traffic light turned to amber. Different collision avoidance warnings were compared for their effectiveness.

Generally the method of visual occlusion is versatile and allows standardisation of certain aspects of distraction across subjects. It is, however, not feasible to use this method in an extended field study.

3.5 PDT as Method in Simulator and Field

Another method that has been used in several studies over the recent years is the peripheral detection task (PDT). This method is only described briefly here, because its main purpose is to measure workload, even though it has been claimed to measure distraction as well. The PDT measures the ability to detect a visual stimulus in the peripheral field of view. Variations exist in the exact implementation of the task, but in general a small red stimulus (e.g. a reflection of a an array of LEDs in the windscreen) is presented at a horizontal angle of between 11° and 23° to the left of the participant (in some studies slightly different values are used). The stimulus is present for a short while (1–2 seconds) and the participant has to acknowledge the presence of the stimulus by pressing a micro switch attached to the index or middle finger of the dominant hand. The stimuli are presented with an inter-stimulus interval of three to five or six seconds. It is claimed that the task requires little conscious attention and can be performed without turning the head or gaze towards the stimulus. Both reaction time and hit rate are seen as indicators of the attentional demands of the environment – the lower the hit rate and the longer the reaction times, the more demanding are the driving task and other tasks that the driver may have to perform. The PDT was described first by van Winsum, Martens and Herland (1999) and has then been used rather extensively, both in the field and in the simulator (see e.g. Harms & Patten, 2001, 2003; Jahn, Oehme, Krems, & Gelau, 2005; Martens & van Winsum, 2000).

The PDT has been found to be sensitive to changes in driving workload and also in workload increases that result from the use of an IVIS. It was found to be sensitive to both visual and cognitive inattention. It has been pointed out that the PDT is not as resource demanding as other secondary tasks that have been used to measure workload. Further advantages of the PDT are that it can detect short peaks in workload, and that data analysis is simple and straightforward. The equipment is not expensive and the task is easy to explain and perform, which allows the use of the method in field studies.

The PDT can be criticised, however, for still being an additional task that the driver has to perform. It is not clear how performance of the PDT in integration with further tasks affects the performance of all tasks that have to be executed, and if there are integrational costs. Especially if another manual task has to be performed there can be interference between using one's hand for the other task and at the same time using the index finger for acknowledging the PDT stimuli. Here it makes a difference whether the driver is right- or left-handed, because IVIS placed in the middle console usually are operated with the right hand, and the PDT micro switch is usually mounted on the dominant hand. If buttons have to be pressed when performing an IVIS task, the wrong finger may be used inadvertently for both the PDT task and the IVIS task due to motor interference.

3.6 Questionnaires/Polls/Focus Groups

In order to assess more subjective aspects of distraction, it is possible to conduct telephone polls or to send out questionnaires. Focus groups can also be arranged. Especially the former two alternatives are relatively cheap and allow collecting data from many participants. As answers to questionnaires and polls can be rather anonymous, there is a chance that truthful answers will be obtained. Obviously it has to be taken into account that the participants that choose to answer might not be representative for the whole group, and that they still might answer according to social desirability. Additionally it is not clear to which extent people are able to give truthful introspective accounts of their behaviour, especially when it comes to at least partly unconscious behaviour like distraction.

One poll was conducted by the NHTSA in the beginning of 2002 in the United States. 4,010 drivers that were contacted by telephone answered questions relating to distracted and to drowsy driving. Therefore the data obtained are self-reported responses.

The interviewees were selected randomly from the total driving population in the United States. The interview lasted for about 18 minutes. Here some answers connected to distracted driving are reported.

The interviewees were asked about twelve potentially distracting behaviours, and whether they themselves engaged in these behaviours. 81% talked to other passengers and 66% changed radio stations or looked for CDs or tapes during at least some driving trips. About half of the drivers said that they at least sometimes were eating or drinking while driving, while about one fourth said that they answered or placed cell phone calls or dealt with children in the back seat. Other activities like reading a map, personal grooming, reading printed materials, responding to pager or beeper, using wireless internet access or using telematics were undertaken by about one tenth of the drivers or fewer.

Around 14% of the drivers who have been involved in a crash attribute the crash to distracted driving. This result is interesting in comparison to the findings in the 100-car study described above, during which it was shown that almost 80% of all recorded crashes can be at least partly attributed to driver inattention (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005). This shows that self-reported data should not always be taken at face value, but also that it has to be defined clearly what is meant by "distraction". This fact is also corroborated by the finding that people who themselves engage in "distracting behaviour" usually judge this kind of behaviour to be less dangerous than those who do not engage in the same behaviour. In general males were less likely to judge distracting behaviours as being dangerous than females.

In Canada a yearly telephone survey is made by the Traffic Injury Research Foundation (TIRF), which is called "Road Safety Monitor" (Beirness, Simpson, & Desmond, 2002). A random, representative sample of Canadian drivers is selected. Driver distraction has recently been included in the list of behaviours deemed to be risky and is therefore part of the survey. Of 4,670 households contacted in which a person was asked to participate, 1,214 (26%) completed the interview, which might give rise to the question as to whether the answers might be biased. The results from the poll are presented below.

In the report aggressive and distracted driving are being juxtaposed as the former being dangerous behaviour in which people willingly engage, because they want to, while the latter is unintendedly dangerous behaviour. That means that the actor is unaware that he or she is actually engaging in dangerous behaviour, which could be due to inadequate information, false beliefs or another type of misunderstanding.

Only 37% of the interviewed Canadians believe distraction to be a serious problem, as compared to other road safety issues like aggressive driving (67%), running red lights (72%) or speeding (60%). The only exception is cell phone use (also listed as driver distraction), which 64% of the Canadian population believes to be dangerous. Also, in the Canadian population women are more concerned about distracted driving than men. In the public opinion using cell phones is the driver distraction par excellence, and also here it is found that more men use phones, while more women consider cell phone use dangerous.

3.7 Correlation Studies/Accident Analyses

Correlational studies are studies in which, for example, the occurrence of certain distractors is correlated with the occurrence of crashes or incidents. For this type of study a good database is needed, and the statistical data which are used should be as accurate as possible. This is not always easy. Additionally, correlation does not imply causation. Both variables could be influenced by another variable, which was not taken into account. Still, if the quality of the data used in the study is good, valuable information can be gained. With regard to distracted driving, probably the only data available in databases come from in-depth accident analyses.

Accident analyses are usually hindsight studies of crashes. It is tried to gain as much information as possible about the variables concerned with the crash. Often correlational studies are conducted across many analysed accidents.

Accident analyses have the advantage that they are directly concerned with crashes, therefore there is no need to argue whether a certain indicator is safety relevant or not. Usually the analyses are performed on large databases that are based on police reports. In some cases especially trained investigation teams are dispatched in order to collect in-depth information from the accident scene and the involved people. Once the database exists it is possible to access a relatively large amount of data within a rather short time.

Drawbacks of accident analyses are that they have to be based on the available data, which can have been collected with different methods. Since the data usually were collected with another purpose in mind, a database study on e.g. distraction might be confronted with a lot of missing data. The sample size obviously depends on the size of the database and on the amount of relevant information within the database. Usually it is not possible to gain additional data, one has to use what is there, and the interpretation is not always easy. At least part of the data can only be gained by interviewing either the victims of the accident (who might have legal interests to give biased answers) or witnesses. Therefore it is difficult to gain objective information, and most accident reports are, due to their retrospective nature, to a certain extent conjectural. Another problem is that there is no baseline available, meaning that from a database it can only be gleaned which factors were present during the crash, but it is unknown how often they occur during normal driving. Therefore it cannot be determined whether a certain behaviour or aspect is overrepresented during crashes.

Distraction has more and more become an issue of concern for accident investigators over the past decades. It entered the National Automotive Sampling System (NASS) database in the United States in 1982 as subcategory of “driver related factors”. By now it is featuring in several accident database analyses. Several such analyses are reviewed in Wallace (2003), and practically all come from the United States.

The following database analyses have mainly been concerned with distraction, and their results are presented briefly in the following paragraphs.

Wang, Knipling and Goodman (1996) report the results of the Crashworthiness Data System (CDS) data collection with respect to driver inattention-related crashes (passenger vehicle towaway crashes in the US). This database was established in order to gain more in-depth insight into driver inattention and its relation to crashes. The authors investigated the files of 4,536 crashes that occurred in the year 1995. In total 7,943 vehicles were involved in these crashes. It is claimed that the data are broadly representative for the US passenger vehicle towaway crashes, and that the investigations are more in-depth than in many other databases. The authors report that 13.3% of the CDS crashes had distraction as a contributor, an additional 9.7% had to do with the "looked but did not see" phenomenon, and in 2.6% of the crashes at least one driver was either sleepy or had fallen asleep. Therefore 25.6% of all passenger vehicle towaway crashes in the US involved driver inattention. This estimate is stated to be conservative. Younger drivers were overrepresented in sleepiness-related crashes, as were male drivers. Female drivers were overrepresented in the "looked but did not see" crashes.

Stutts, Reinfurt, Staplin and Rodgman (2001) give a tentative listing of different types of distractions, and the percentages with which they occur in north American crashes, also based on the NASS Crashworthiness Data System. According to their analysis around 12% of the drivers that ended up in a towaway crash were distracted (in this figure the "unknown driver status" cases are eliminated). Of those, around 30% were distracted by persons, objects or events outside the car, around 35% were distracted by something inside the car, the rest was classified as "other distractions" or "unknown". The data seem to be a bit vague, but a conclusion might be that distractors both outside and inside the car have to be considered when investigating distraction and possible countermeasures, because they each represent at least about a third of the distraction related crashes.

The study suggests in accordance with others that there are age differences with respect to frequency of distraction and the kind of distractor one is susceptible to. Gender differences were not pronounced with only a small tendency for males to be more likely to be distracted during a crash.

4 Glance Behaviour During Driving

There are many studies which are concerned with for how long drivers look away from the road. If glance duration away from the forward roadway is used as operational distraction criterion, those studies can be used as a basis for determining the necessary glance duration for distraction.

The International Organisation for Standardisation (ISO) has put forward a standard in order to "give guidance on the terms and measurements relating to the collection and analysis of driver visual behaviour data" (ISO, 2002, p. iv). The standard was published in 2002, therefore only few of the studies quoted below could have adhered to the standard, and it is not clear whether they did. Some definitions of glance behaviour aspects are presented here anyway, in order to provide a reference on how certain terms should be used, and to stress the importance of defining the investigated variables well (Table 3).

Table 3 Selected terms and definitions of glance behaviour during driving from the ISO standard 15007-1:2002 (p. 2 f.) with comments.

Term	Definition	comment
dwell time	sum of consecutive individual fixation and saccade times to a target in a single glance	a glance to a target can, thus, consist of several fixations and saccades
glance duration	time from the moment at which the direction of gaze moves towards a target (e.g. the interior mirror) to the moment it moves away from it	the transition to a target and the dwell time on the target are included in the glance duration, but not the transition away from the target
glance frequency	number of glances to a target within a pre-defined time period, or during a pre-defined task, where each glance is separated by at least one glance to a different target	
Target	pre-determined area within the visual scene, e.g., a rear-view mirror	
Transition	change in eye fixation location from one defined target location to a different location	
transition time	duration between the end of the last fixation on a target and the start of the first fixation on another target	

The ISO standard suggests to present for example the "percentage of extended duration glances (e.g. glances over 2 seconds)" (p. 4). The notion that glances away from the road that last for more than two seconds are extraordinarily long and hazardous is a recurring statement in the literature.

According to Rockwell (1988, p. 319), a glance is a “series of fixations in the same target area”. This definition corresponds well to the ISO standard. Rockwell defines glance duration as the “time off the roadway to attend to a target, e.g. mirror, stereo, speedometer, etc.” (ibid.). In his study Rockwell recorded more than 6,000 off road glances to the radio and more than 4,000 glances to mirrors and speedometer for 106 participants. Most trial drives were carried out on urban expressways with light to moderate traffic at speeds of 45 to 55 mph. Rockwell found the average glance duration to the radio to be between 1.27 s and 1.42 s duration in three different studies, with an average standard deviation across the studies of around .5 s. When several glances were performed in a row, the duration of each single glance remained approximately the same. Mirror check durations averaged around 1.0 s. The longest glances were recorded for the right mirror, then the left mirror, then to the rear view mirror in the middle. Speedometer checks lay on average at around .80 s.

Radio operation requires visual discrimination as opposed to mirror checks, which are simple detection tasks. When drivers are asked to perform a discrimination task in the mirror, the glance duration increases to about the level of the radio glances. Rockwell found a positive correlation for the duration of radio and of mirror glances, which means that some drivers generally have a tendency for longer glances and others for shorter. The 95th percentile of radio glances lay at 1.59 s, but occasional glances as long as around 3 s were recorded. Rockwell found significant gender differences for average glance durations with females having shorter average glance durations. Older drivers (> 45 years) show slightly longer glance durations than younger drivers (< 35 years). Longer glances can be provoked by tiny typeface and bad legibility, but more complicated tasks usually only increase the number of glances, not the duration. The factors which influence glance duration substantially are traffic density and highway geometrics. In high traffic and in curves average glance durations decreased by around 20%. Rockwell’s major conclusion is that glance duration is “impacted more by the demands of the driving task than by ‘in car’ targets and their visual characteristics” (Rockwell, 1988, p. 323). Rockwell also suspected that glance duration is a relatively consistent measure of drivers’ visual performance.

Dingus, Antin, Hulse and Wierwille (1989) measured the mean duration of single glances for different tasks, and found them to lie between 0.62 s (checking actual speed) and 1.66 s (check name of cross street). In line with other research it was found that drivers rather glance back to the road before they continue with their task when a glance duration of around 1.2 s is reached.

Wierwille, Hulse, Fischer and Dingus (1988) observed, that the likelyhood of the driver’s gaze being on the road instead of on a navigation system increased with increased roadway difficulty. The glance length to the forward view increased, too.

Wierwille (1993) quotes several studies, which show an increased in-car single glance duration for older drivers. The transition time between focusing on the in-car task and the forward view also increases with age.

Hada (1994) found during a pilot study that drivers’ visual behaviour did not show any significant differences with respect to driving in darkness vs. driving during daylight hours. His main study was therefore carried out during daylight only. In the study drivers were instructed to look at certain targets in the car as long as and as often as they felt safe to do so. The targets were installed in the HUD-area, the center of the instrument panel, and the top of the center console. The roads on which the participants drove were mostly flat and straight. The median glance duration over all targets and road types (expressway, rural, suburban) lay at around .8 s (mean glance duration: .99 s), with rather small variations for targets. There was more variation with road type. On expressways median glance durations were longest (.86 s), while they were shortest on suburban streets (.68 s). Generally the glance distribution was a skewed normal distribution (skewness[1] = .67, kurtosis[2] = .52). For gender, age and location complicated interactions were found which will not be discussed here. The results of this experiment are in accordance with the results of other experiments measuring glance duration.

Wikman, Nieminen and Summala (1998) conducted a study in which the participants drove a 126 km long route in normal traffic while performing several secondary tasks. Glance duration was determined by frame-by-frame video analysis. No significant effect of gender or driving experience on in-car glance duration could be found. However, glance duration depended significantly on task type, ranging from 1.02 s for a radio station search task to .91 s for changing a cassette tape. The variation in glance duration was found to vary with experience, with more experienced drivers showing a significantly smaller variation (.34 s) than less experienced drivers (.44 s). Variation in glance duration varied with task type, too. A special analysis of the longest in-car glances was performed. Glances of more than 2.5 s and of more than 3 s were analysed. It was found that inexperienced drivers generally stand for most of the longest glances, and that males are more prone to glancing away from the road for a long time than females, even though the gender effect was not significant. The total percentage of those extremely long glances was well below 5% of all in-car glances. The longest glances were about 4.5 s long.

Green (1999) reports a Japanese study, in which median glance times of 2.0 s and more are reported. This large difference to most other reported studies is considered to be connected to the instructions given to the participants, which read that drivers should look at the in-car targets for ”as long as possible until you feel uncomfortable” (quoted in Green, 1999, p. 29). This fact underlines how important it is to be clear about the instructions given to the participants. In Green’s (1999) report many other studies are quoted, that in general have similar glance times as those in the studies quoted here. Additionally Green mentions that a large number of consecutive glances (high total glance times) very likely leads to lane departures. He quotes several studies pointing in this direction.

Sodhi, Reimer and Llamazares (2002) investigated glance behaviour in a field study with a head-mounted eye tracker. The amount of data obtained is relatively limited, but the results go in the same direction as those found by Rockwell (1988). The coding is not perfectly clear, as the measures are split into ”average length of off-road glances”, ”average on-road glance” and ”movement time” for each respective secondary task. It is not clear whether one has to consider the ”average length of off-road glances” only, or add the ”movement time” to that, and if so, whether it has to be added once or twice

[1] positive skew: right skew, meaning that the higher tail of the distribution is longer (the peak “sits” more on the left side); therefore the mean value is larger than the median (50th percentile) (definition from http://en.wikipedia.org/wiki/Skewness)

[2] positive kurtosis: the distribution has a more acute "peak" around the mean (that is, a higher probability than a normally distributed variable of values near the mean) and "fat tails" (that is, a higher probability than a normally distributed variable of extreme values) (definition adapted from http://en.wikipedia.org/wiki/Kurtosis)

(moving off the road and moving back to it). Therefore the average duration of off-road glances for radio manipulation was at least .76 s and at most 1.52 s. For the rear view mirror (with discriminating task) these measures were .96 s and 1.60 respectively, and for the odometer the average duration of off-road glances was minimally .69 and maximally 1.35 s. The average on-road glance (in between off-road glances) was on average around .5 s.

Chiang, Brooks and Weir (2004) conducted an on-road study in which glance duration was analysed with respect to entering addresses in a navigation system. Ten participants drove in real traffic with the instruction that their primary task was to maintain vehicle speed, to maintain a safe following distance, and to keep the vehicle in the lane. A video analysis was performed in order to determine glance time. While the address entry was in progress on city streets the participants spent 55% (52% on freeways) of the time looking at the navigation display and 23% (25%) of the time looking at the road scene, while the remaining 22% (23%) of the time were spent looking at other things, like mirrors or the dashboard. Depending on how many keystrokes were performed during one glance to the navigation system the mean glance duration varied. If one keystroke was performed the participants glanced at the display for 1.0 s on average, while the mean display fixation time lay at 1.5 s for two keystrokes, the total average was 1.2 s. In total 94% of all fixations were shorter than 2.0 s. During destination entry the fixations on the road lasted on average .47 s with 95% of the roadway fixations below 1.2 s. The off-road glances were, therefore, longer than the on-road glances in between.

In Karlsson’s (2005) study the average glance duration away from the road and onto a display mounted on the middle console was 2.11 s, with a median of 1.97 s. Eighteen per cent of the total number of glances away from the road were longer than 3 s. The investigated response to a distraction countermeasure in that study was a steering reaction. It was found that the participants reacted on average before they looked up. Karlsson (2005) gives three possible explanations for this finding. Either there is a lag in the eye tracking system (he used SmartEye’s system), or his criterion was too sensitive, so that small involuntary steerings were considered as reaction, or, most interestingly, that the participants were able to monitor the road even though they looked away from it. Here a discussion is possible as to whether this would also happen during ”true” distraction or only in a setting more corresponding to ”high workload due to secondary task”, like the one in the described study. Generally Karlsson’s (2005) glance times are considerably longer as compared to those found in the literature reviewed above. Whether this is an artifact of the way to measure glance duration, or whether it is related to the study’s being conducted in a simulator and not in the field, or whether it is a result of the effort to direct the drivers’ attention away from the road, or if it has any other reasons is not sure.

Dukic, Hanson, Holmqvist and Wartenberg (2005) conducted a field experiment in which drivers were asked to manipulate certain buttons while driving. The glance duration was measured, and it was found that 49.0% of the glances took less than 1 second, 88.3% of the glances were shorter than 1.6 seconds and 98.4% of the glances were shorter than 2 s. This is another indication for the fact that glances off the road that last longer than 2 s are an exception and for most drivers under most circumstances unacceptable.

Most studies are only concerned with the duration of glances away from the road, but it is also of interest to investigate for how long drivers look back at the road before looking away again, if they have to perform multiple glances. One study that investigated this question at least indirectly was performed by Tsimhoni (2003) in a driving simulator at UMTRI. He measured the total task time to perform an in-vehicle task both while parked and while driving on less or more demanding roads. Amongst other measures the total glance time was taken, which can be subtracted from the total task time to yield the duration for which the driver looked back at the road between glances. It was found that the total glance time (the accumulated time that the participants looked at the in-car display) was not significantly influenced by road curvature. Older participants had significantly longer total glance times than younger participants ($p < .05$). It has to be noted that total task time (the duration of completing the in-car task, including both glances at the display and intermittent glances at the road) increased significantly from being parked over driving on straight roads to moderate and high curvature. This indicates that the glances on the road in between the glances off the road become longer with increasing difficulty of the driving environment.

On sharper curves the single glance duration decreased (mean glance duration for straight roads was 2.3 s, for moderate curves mean glance duration was 1.5 s and for sharp curves it was 1.3 s). Single glance durations were rather long as compared to other studies, which might have to do with the study's being performed in a simulator instead of in the field. The average glance duration to the road in between glances away from the road was .75 s for straight roads, .85 s for moderate curves and 1.0 s for sharp curves. The duration ratio between glances to the display and to the road decreased significantly from 3.4 on straight roads to 1.5 on sharp curves. These data can be interpreted such that on more demanding roads drivers need more time viewing the road to update their information enough to feel safe to look back to the display again. It cannot be said, though, whether they update their understanding of the outside scene completely, or whether they only check if some key features still correspond to their expectations. It is interesting, though, that the glances back to the road are on average shorter than those to the in-car display, which could be interpreted such that the drivers put more effort into the secondary task than into driving. Another interpretation might be that normal traffic is viewed as detection task whereas in-vehicle tasks tend to be discrimination tasks. Also, there have been studies showing that people feel a psychological pressure to complete an uncompleted task (Mandler, 1975).

A very detailed overview of different glance times found for different tasks with many further references was published by Green and Shah (2004).

5 Glance Duration and Traffic Safety

Many studies only focus on glance time per se, describing how much time a driver spends looking at the traffic scene vs. looking at targets within the car or targets not relevant to the driving task. There are some studies, however, that directly consider the impact of glancing away from the road on traffic safety. One safety indicator that is used in several studies is ”lane departure”. Green (1999) states that the risk for a crash increases, the more likely the drivers are to leave their lane. Senders, Kristofferson, Levison, Dietrich and Ward (1967) have postulated a model on driver information acquisition, which shows that the amount of information that the driver has about the traffic situation decreases with an increasing number of glances on an in-car target, in spite of intermittent glances back to the forward roadway. This indicates that the glances to the road scene are too short to get back ”into the loop” completely.

Zwahlen, Adams and DeBald (1988) conducted a closed-track experiment during which the participants had to operate a simulated CTR touch panel. They wanted to investigate whether the statement is true that an increased number of glances inside the car in fact leads to deteriorated lane keeping. The placement of the mockup CTR (either high or low on the instrument panel) had no significant influence on the number of glances back to the road. In one condition participants were allowed to look at the road as often as they found necessary, in the other condition they were not allowed to do so. The mean completion time for adjusting the radio for all conditions combined was 5.0 s (SD = .98 s), for radio and climate control combined the mean completion time was 8.93 s (SD = 1.63 s). During the radio tasks participants looked up 2.7 times on average, and during the climate task (without the radio task) 1.4 times on average. From the measured standard deviation of the lateral position of the car it was calculated that on a 12 ft (3.66 m) wide lane under ideal conditions (calm, dry road, sunny) there would be a 3% chance of the vehicle’s laterally deviating out of the lane while the driver was operating the CRT panel (vehicle bredth 6 ft, which equals 1.83 m). For a lane width of 10 ft (3.05 m) the chance of lane departure would rise to 15%. Zwahlen, Adams and DeBald (1988) stress that these estimates were made for ideal conditions and warn for higher lane departure probabilities under less favourable circumstances, but it has to be taken account that the study was conducted on a closed track, which might have led to more risk taking on the participants’ part.

Summala, Nieminen and Punto (1996) let their participants perform a visual task, which constantly kept their foveal vision on an off-road position. The participants could only use peripheral vision to keep the vehicle in a straight lane. They managed to do so, but experienced drivers performed better than inexperienced drivers. The more eccentric the position of the secondary task, the lower was lane-keeping performance.

In a study conducted by Wikman, Nieminen and Summala (1998) larger lateral displacements for longer in-car glances were found. Extreme lateral displacements were more frequent for less experienced drivers, who also had longer single glances than more experienced drivers.

In a test track study Tijerina, Parmer and Goodman (1999) found, in accordance with other studies, that glance frequency to the in-car task device was highly correlated with task time, and that those two measures were moderately correlated with the number of lane exceedences. No correlations between those measures and mean glance duration were found. This points to the conclusion that not so much the single glance duration but more the total glance duration away from the road is important for traffic safety, because single glance duration does not vary substantially.

Tijerina, Johnston, Parmer, Winterbottom and Goodman (2000) investigated the 15-second-rule, a rule postulating that a task that can be finished within 15 s while the car is stopped would be safe to perform while driving, of course with intermittent glances on the road. The study was conducted on a test track where other non-confederate traffic was present. Each participant performed different entry tasks on four different route guidance systems. The tasks were performed both when the vehicle was parked and when the participant drove the vehicle at the same time. Additionally lane exceedence per trial was counted. Regression analyses were performed for the corresponding static and dynamic task pairs, and a positive correlation was found ($R^2 = .39$), the standard error, however, was large. A linear regression was also computed for completion time while parked and number of lane departures ($R^2 = .27$), and for completion time while driving and number of lane departures ($R^2 = .43$). In both cases the standard error was substantial. Even though more than half of the variance in the number of lane departures is not accounted for by the duration of the in-vehicle task it can be stated that longer task durations lead to a higher likelihood of exceeding the own lane.

Tsimhoni (2003) conducted a simulator study, which has already been mentioned above. He found that total task time increased significantly with a more complex driving task (sharp curves vs. straight road vs. being parked, as control). This was a result of the participants' making longer glances at the road for more complex road conditions, while the average glance duration at the in-car display decreased. Even though the participants seemed to adapt their glance behaviour to the road conditions, still driving performance degraded with a more complex environment (more lane departures), and more errors were made in the in-vehicle task. It has to be noted, though, that more lane departures were made on curvy roads than on straight roads even without a secondary task. Generally it was found that the total glance time remained relatively constant across all conditions.

Driver distraction is not only related to an increasing risk for lane departure, but also to an increase in reaction time and degradation in other measures of driving performance. This has been shown by Lee, McGehee, Brown and Reyes (2002), who distracted the participants with a detection task while driving a high-fidelity simulator. A lead vehicle braked periodically, and the driver had to respond quickly in order to avoid a crash. In the distracted condition the participants released the accelerator on average .4 s later than when they were not distracted.

Lamble, Laakso and Summala (1999) conducted a test-track study in which the participants had to follow a confederate vehicle while they constantly monitored a display placed at different eccentricities inside the car. The lead vehicle decelerated by releasing the accelerator, but without pressing the brakes, and the participants were instructed to brake as soon as they noticed that the lead vehicle was decelerating. TTC decreased and reaction time increased with increasing eccentricity of the foveal task, it was found, however, that a shorter initial headway produced lower detection thresholds, which was explained with the relative retinal size of the lead car.

Horrey and Wickens (2004) found increasing reaction times to critical hazardous events for head-down displays as compared to head-up displays for the same tasks, which were performed in a fixed-base simulator.

Recarte and Nunes (2000) used an automatic eye tracker in an on-road study during which the participants performed mental tasks of verbal and of spatial imagery nature.

For the verbal task words had to be repeated according to a rule, and for the spatial imagery task certain characteristics of letters had to be determined (rotatable along certain axes or not, open or closed). It has to be noted that the driver is not required to look away from the driving scene to perform these tasks, therefore the distracting nature of the task with respect to the definition above can be disputed. The study has been included here anyway, because it uses an automatic eye movement registration device, and because many researchers consider “cognitive inattention” as a certain type of distraction.

Different routes of different difficulty levels in terms of traffic density and curvature were driven. The design was within subjects for the distraction tasks and traffic density, and between subjects for highway vs. ordinary roads. Pupil dilation was larger when the participants worked on a secondary task than without secondary task. Fixation durations were significantly shorter during the verbal task (ca. 300 to 340 ms) than during the spatial imagery task (ca. 370 to 430 ms), with the no-task condition in the middle.

Further analyses showed that the longer mean fixation durations are a result of a higher variability in fixation duration with some very long fixations, rather than a general increase of fixation duration. This effect is called “freezing of the eye” in a certain location. Neither road type nor task type influenced the horizontal distribution of fixation locations, but the horizontal variability of gaze direction was significantly lower for the imagery task than for the verbal task. Both task conditions showed significantly lower variations in horizontal variability of fixation location than the glances in the condition without additional task. The vertical distribution of fixation locations was influenced both by road type and task type. Road type variations are explained with environmental factors.

Performing an additional task while driving led to a rise in gaze direction with approximately .5° to 1°. No differences were found between task types. The vertical variability of gaze direction showed the same significant patterns as the horizontal variability of gaze direction. When the horizontal and vertical variability were considered together, the greatly diminished size of the so-called visual inspection window could be demonstrated for performing a mental task, and especially an imagery task.

Task type was not found to have a significant effect on speed on the highway, but on the ordinary roads speed was found to increase while the participants performed the mental tasks. This was attributed to a loss of control and a reduced number of glances to the speedometer.

Fixations on mirrors and speedometer were found to be about .1 s shorter than ordinary fixations. For normal highway driving 14 out of 1,000 fixations were directed at the interior mirror, for the verbal task this number decreased to 4 out of 1,000 fixations, and for the spatial imagery task to 2 out of 1,000 fixations, which was a significant reduction. Analoguous results were found for the left mirror and very clearly for the speedometer.

During ordinary highway driving 4% of the glances (3% on ordinary roads) were directed at the speedometer, but less than 1% of the glances were directed there when a task was performed. The authors separated the effect of visual narrowing and a reduced number of glances to mirrors and speedometers by eliminating all glances to those objects and re-analysing the data. Visual narrowing was still present, even though obviously somewhat attenuated. This implies that the reduction of the visual inspection window cannot be explained completely by a decrease in glances to mirrors and dashboard.

Zhang, Smith and Witt (2006) used the FaceLAB system (www.seeingmachines.com) in order to assess glance direction automatically. They conducted a simulator study during which the participants were distracted with a self-paced visual task with different levels of difficulty. The participants followed a car both in a highway condition and in a rural road condition. At predefined points the lead vehicle braked, and twelve dependent variables were measured.

Two new glance variables were developed. *Weighted gaze variability* was calculated following Recarte and Nunes's (2000) definition of a rectangular visual inspection window. The dimensions of such a rectangle are proportional to the standard deviations across fixations on the horizontal and vertical axes. The standard deviation of attention pitch (rotations around the side-to-side axis, thus, vertical gaze variation; FaceLAB variable) was multiplied by four and then multiplied by the standard deviation of attention yaw (rotations around the vertical axis, thus, horizontal gaze variation). The result was called *weighted gaze variability*, measured in degrees squared. The square root of the sum of the squared attention yaw angle and squared attention pitch angle was defined as *weighted gaze vector* (in degrees), which reflected the distance between the focus of expansion and the attention coordinates.

A multivariate analysis of variance showed that both road type and distraction level had significant effects on the dependent variables. Higher distraction levels lead to higher felt workload as measured by the NASA-TLX. Standard deviation of lane position, lane departure duration and steering entropy increased for increasing distraction levels. Glance freqency, the proportion of off-road glance time between the time when the lead vehicle braked and when the accelerator was released, and total glance duration increased with increasing difficulty of the distraction task, but mean glance duration was not influenced by the level of distraction and remained under 2 s.

Weighted gaze variability and weighted gaze vector were found to increase with increasing level of difficulty of the distraction task. Reaction times for accelerator release increased with increasing difficulty of the distraction task, and they were longer on the highway than on the rural road. Reaction times were also found to be longer on curvy roads than on straight roads, with the effect of curvature being more apparent in the highway condition. The authors reason that an eye glance measure must correlate with reaction time and performance in order to be diagnostic of distraction. A high correlation (.71) was found for the accelerator-release reaction time and the proportion of off-road glance duration between when the lead car braked and the moment of accelerator release.

For the remaining glance variables a window of 60 s before the time when the lead vehicle braked was used. Glance frequency was significantly and positively correlated with steering entropy. A positive correlation existed with the other driving performance variables, too, but without reaching statistical significance. Total glance duration was significantly correlated to all performance measures, namely steering entropy (.92), lane departure duration (.65), standard deviation of lateral position (.73) and accelerator-release reaction time (.60). Mean glance duration was not significantly correlated with the performance measures, which might be explained by the relatively small range of mean glance durations. Weighted gaze variability and weighted gaze vector were highly correlated with all performance measures and thus considered to be diagnostic of visual distraction. The robustness of these correlations was tested for several shorter time windows ranging from 1 to 30 s. Except for steering entropy the results were similar to those with a time window of 60 s. Further analyses showed that a time window of .25 s or more was needed in order to obtain reliable correlations.

The main conclusion drawn by the authors is that an increased level of visual distraction indeed contributes to decreased driving performance. The authors advocate the variables weighted gaze variability and weighted gaze vector as distraction indicators. They realize, however, that data obtained under real driving conditions may not be as reliable as those from their simulator experiment and suggest total glance duration as a surrogate diagnostic measure to assess the level of visual distraction. The authors suggest a field study with naturally occurring distraction as a means to verify their results from the simulator.

The reported results indicate that several consecutive glances away from the road worsen the performance more than a single glance of the same duration as each of the consecutive glances. This means that by looking back on the road briefly between glances away from the road the driver cannot update his mental image of the situation enough in order to be fully back in the loop. It seems like the drivers are satisfied to find that things are ”more or less” as expected, so that they can carry on with the in-car task. It remains to be investigated how long a driver has to focus back onto the road in order to get back into the loop completely, and if that time period varies for different situations (different complexities of the traffic scene), and if it depends on the fact whether the in-car task has been completed successfully (which would allow the conclusion that the driver is not mentally engaged in the task any more). Experience could also play a role in the time needed to get back into the loop, but it is possible that more experienced drivers make do with shorter glances back to the road before returning to the in-vehicle task.

Only in recent years have remote eye trackers been used in research concerned with driver distraction. Just like in the studies, in which eye movement data were analysed manually, it was found that there exists a relationship between off-road glances and driving performance measures. So far the number of studies that use an algorithm for distraction detection that operates in real time is limited. No such study has been conducted in the field under natural conditions yet.

6 New Approaches of Measuring Distraction

With the advance of remote eye trackers that allow a real time assessment of glance direction and duration, new ways of measuring distraction have appeared. Several different concepts have been tested in driving simulators, and all of them do not only consider the current glance duration, but also the glance history of a certain time span that passed before. In this way the fact that multiple glances have detrimental effects on safety are taken into account.

The so-called “attention budget” is a concept used by Holmström and Johansson (2003) and Karlsson (2005). The idea is that in order to update one’s knowledge about the actual traffic situation fully one has to look at the road at least for a certain amount of time. Therefore, when measuring distraction operationalised by glance off road, with the purpose of warning the driver when the glance off road has been too long, not only the single glance duration is considered. Rather, a short glance back to the road after a longer glance off the road leaves the driver with an “attention deficit”, which means that the inattention warning can be issued for a subsequent shorter glance off the road. In practice the driver is assigned a certain “attention budget” which he can deplete by either a single long glance or repetitive short glances. While looking away from the road the budget is decremented, and for looking back at the road it is incremented. Further delays for incrementing and decrementing can be added that account for glances to the mirror, the speedometer, etc. Increment and decrement rates can be modified depending on driver and/or environmental characteristics.

Even though it would possibly be more accurate to work with ”information bits”, time was used in the mentioned studies. This is easier to operationalise, because it is quite difficult to measure the amount of processed information in a human being and the amount of information in a traffic scene. Furthermore, it is not clear whether a driver’s knowledge is necessarily better when he has processed more information, because it is important to process the relevant information. This is also true for time, of course, meaning that it is possible that experts need less time to gather all relevant information than beginners do. Also, it is thinkable that drivers need more time to collect the information in complex traffic environments as compared to simple ones, as indicated in Tsimhoni’s (2003) study. Other factors like the state of the driver, time of day, etc. can play a role, too. The more that is known about these factors, the more detailed can the increments and decrements of the attention budget be set. Whether this concept is a useful model of driver attention will be investigated in a smaller-scale field operational test within the IVSS project Inattention and Drowsiness (http://www.ivss.se/templates/ProjectPage.aspx?id=214).

Victor (2005) and Victor et al. (2005) use a comparable concept called Percent Road Centre (PRC). It is defined as follows (Victor, 2005, p. 35): ”The percentage of gaze data points labelled as fixations during a fixed period of time (e.g. one minute) that fall within a road centre area. The road centre area is defined as a circular area of 16 degrees diameter, centred around the road centre point. The road centre point was determined as the mode, or most frequent gaze angle, of each subject’s baseline driving data. …”. A rolling mean of fixations within the PRC is calculated, and when the percentage of fixations within the PRC falls below a certain value a warning is given to the driver. This approach doe not focus so much on the driver’s looking away once (but maybe for a long time), but considers the history of having looked away repeatedly while still including the criterion that the driver looks away at the time when the warning comes; in order to undershoot the criterion the driver has to be looking away from the PRC.

Victor suggests that PRC values of more than 92% can be an indication for cognitive distraction. This would mean that the driver looks *at* the road centre more than usual, thus neglecting the mirrors and what is happening in the periphery (functional tunnel vision). He found supporting evidence in three experimental studies both in simulators and in the field, which showed that higher situational demands led to a gaze concentration on the road centre. Higher difficulty levels of the visual secondary task, however, led to decreased PRC values. Victor collected real time gaze direction data with help of FaceLab.

Assessing driver distraction was not the specific goal of the 100-car study, but it was analysed whether the collected crashes and near-crashes were related to driver distraction. A special report on the impact of driver inattention on near-crash and crash risk was released in April 2006 (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). In order to compare eye glance behaviour in situations directly preceding a crash and during normal driving 6-second-sections of video tape were analysed with respect to how much the driver looked at the road as compared to away from the road. It was found that a cumulative off-road glance duration of more than 2 s within 6 s was significantly related to crash/near-crash involvement.
In the American project SAVE-IT several simulator studies were conducted that made use of the eye tracker FaceLab. Different algorithms were used to diagnose a distracted driver. Donmez, Ng Boyle and Lee (2007) used an algorithm that takes into account the current off-road glance duration (β_1) and a 3 s moving average of the total off-road glance duration in that period (β_2). The relative influence of the current glance duration is the variable α. These factors together determine the momentary value of distraction γ with $\gamma = \alpha\beta_1 + (1 - \alpha)\beta_2$. In the study α was set to 0.2. A two-stage warning strategy was devised with the first warning at $\gamma = 2.0$ s and the second warning at $\gamma = 2.5$ s. In

Figure 1 the relationship between the two β is shown for $\alpha = 0.2$ and $\gamma = 2.0$ and $\gamma = 2.5$. It has to be noted that the current glance is included in β_2 as well, because the current glance is always part of the last 3 s. An earlier study by Zhang and Smith (2004) within the same project had shown that a 3 s moving average of off-road glance duration predicted distraction.

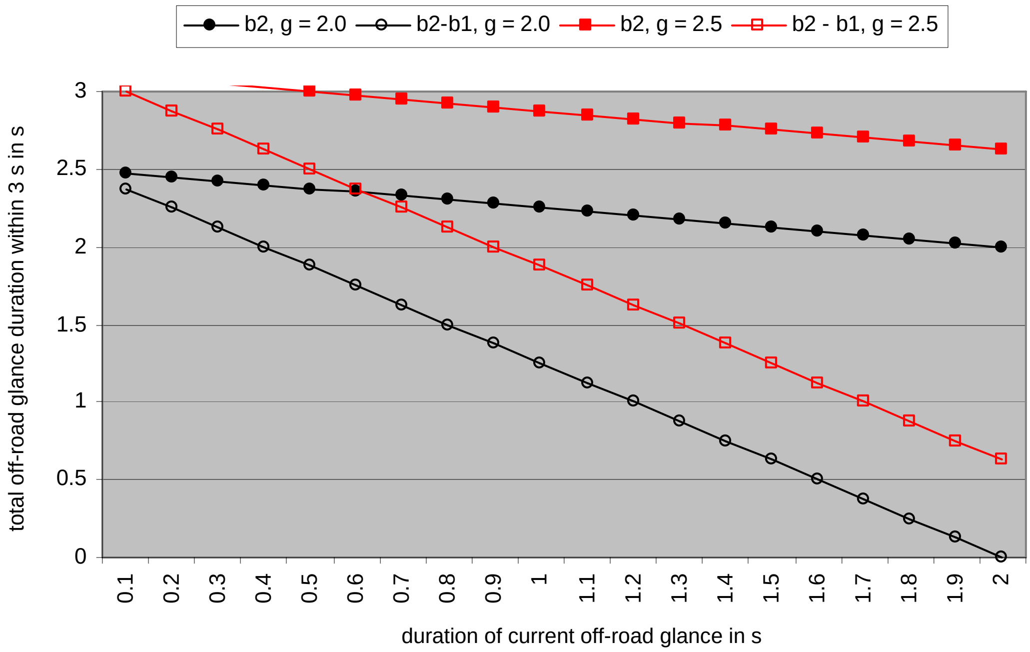

Figure 1 Relationship between the duration of the current off-road glance (β_1) and the total off-road glance time in the last 3 s for α = 0.2 for the first warning stage (γ = 2 s; depicted in black) and for the second warning stage (γ = 2.5; depicted in red). The greek letters are presented as roman letters in the figure.

A further new glance measure that seems to correlate well with performance decrements in driving is the weighted gaze variability discussed above, which was developed by Zhang and Smith (2006). Here, however, no border value that serves as diagnostic criterium for a distracted driver has been set yet.

This measure shows similarities to Victor's *standard deviation of (radial) gaze* (Victor, 2005; Victor, Harbluk, & Engström, 2005), which is defined as the standard deviation of the vector sum of horizontal and vertical gaze components, that is, the square root of the sum of squared vertical and squared horizontal angles. It is thus a one-dimensional angle between the zero intercept and gaze point (Victor, 2005, p. 35). This measure was decreased when participants performed an auditory task both in two simulator experiments and in the field.

It has to be noted that visual distraction and cognitive distraction can produce results going in opposite directions. A visual distractor might, for example, lead to an increased variation in gaze and an enlarged search area, while cognitive distraction can produce the opposite due to functional tunnel vision.

7 Distraction Mitigation Strategies

One major project dealing with distraction mitigation and adaptation of other warnings to driver state is the US project SAVE-IT. The main actors are Delphi Electronics & Safety, UMTRI, the University of Iowa, General Motors, Ford and Seeing Machines. Extensive publications on many aspects of distraction and progress of the project can be found on http://www.volpe.dot.gov/hf/roadway/saveit/docs.html. The publications that specifically address distraction mitigation are published by Donmez et al. (Donmez, Ng Boyle, & Lee, 2006, 2007; Donmez, Ng Boyle, Lee, & McGehee, 2006). Additionally, Donmez et al. prepared a literature review of distraction mitigation strategies for the project SAVE-IT (Donmez, Ng Boyle, Lee, & McGehee, 2004a, 2004b).

Otherwise not much research specifically directed at distraction mitigation strategies has been published until today to the knowledge of the author. Rather, other ADAS and IVIS are evaluated with respect to how much they distract a driver, or how much they can help a distracted driver.

The goals of the SAVE-IT project are both the adaptation of safety warning systems to current task demand, driver state and driver intent, and the development of an adaptive interface to minimise driver distraction in the first place. Experiments were conducted in three driving simulators (Delphi Electronics & Safety, University of Iowa, UMTRI). Adaptability of warning systems is important in order to reduce false alarms and increase acceptance of the driver support systems. It is pointed out that drivers tend to adapt to the circumstances themselves (Donmez, Ng Boyle, Lee, & McGehee, 2004a, pp. 4–8), and that system adaptation and driver initiated adaptation have to fit together. Figure 2 illustrates how different environmental demands and different driver states influence how much attention can be allocated to non-driving tasks without detrimental effects on driving performance. A system that is able to evaluate both driver state and traffic conditions can produce warnings that are much better tailored to the circumstances than a static warning system can.

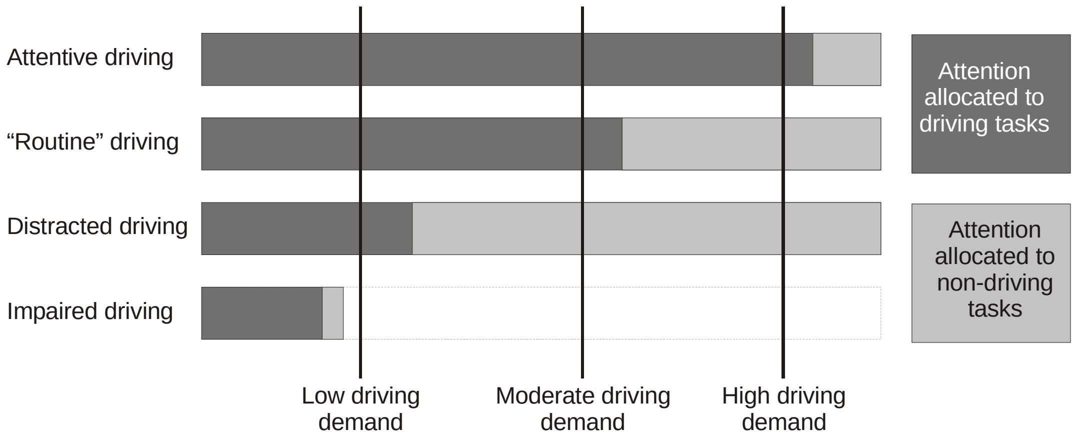

Figure 2 Adapted from SAVE-IT. Relationship between attention allocation to driving- and non-driving tasks, driver state and environmental demands.

When the environmental demands on driving are high, it is necessary that the driver be alert and attentive in order to drive safely. A driver who is as impaired as indicated in the lowest bar in Figure 2 does not even have the attentional resources necessary to meet low environmental demands.

Within SAVE-IT a taxonomy for distraction mitigation strategies was developed, that classifies them as having a high, moderate or low level of automation, and as being driving related vs. non driving related. Within the latter two, the strategies were further split into being system initiated or driver initiated (Donmez, Ng Boyle, Lee, & McGehee, 2004b). An overview is presented in Table 4.

Table 4 Adapted from SAVE-IT. Mitigation strategies classified by level of automation and type of task.

level of automation	**driving related strategies**		**non driving related strategies**	
	system initiated	**driver initiated**	**system initiated**	**driver initiated**
high	intervening	delegating	locking & interrupting	controls pre-setting
moderate	warning	warning tailoring	prioritising & filtering	place-keeping
low	informing	perception augmenting	advising	demand minimising

System initiated, driving related strategies are those that relate to the driving task; they might inform the driver about an upcoming sign, warn for an exceeded speed limit or intervene by starting to brake if time to collision reaches a critical value. Driver initiated, driving related strategies are those in which the driver might delegate speed and distance choice to the adaptive cruise control system, or demand a warning at a certain headway or speed set by the driver, or demand information about the current speed limit. Driver initiated, non-driving related strategies are those that the driver uses in order to increase his performance on the secondary task.

For this report system initiated, non-driving related strategies that tell the driver that he is distracted are of interest. *Locking and interrupting strategies* make interaction with the secondary task at hand impossible by for example locking out the display of a device completely or by interrupting non-driving activities that were begun already. There are risks connected with this rather drastic strategy – drivers might get annoyed, especially in a false alarm situation. They might also try to continue with the task because they did not realise that it was locked or interrupted, which could have serious consequences. *Prioritising and filtering strategies* are those that only let through information according to a priority list devised by the driver. *Advising strategies* tell the driver that he is distracted, but do not take any action themselves. It is possible to build in a hierarchy for the strategies, depending on the current traffic situation or to adapt the timing of the action within one level of automation, or to integrate both approaches.

Almén (2003) examined an advising, system initiated, non-driving related distraction mitigation strategy in the high fidelity simulator at VTI. One cue was an audio alert which consisted of the participant's first name spoken by a male voice in a way that should attract attention. The second cue was a vibration in the car that resembled what is felt when driving on rumble strips. The four tested conditions were "auditory cue only", "haptic cue only", "both combined", and "no cue" as control. As no real time eye tracker was used, the criterion for switching on the distraction warning was time-based only and constant across trials. First a reading task was initiated which was supposed to distract the driver. One second later an event was initiated (an obstacle was placed on the road or the yaw of the car was changed as a simulation of wind gusts). After another second the distraction cue was given, regardless of whether the driver looked at the secondary task display or not. Even though no significant differences between the conditions were found in reaction time, time to collision and headway to obstacle at accelerator release, there was a general trend that the combined cue yielded the best results from a traffic safety point of view. A major problem with the study, however, is the fact that the actual gaze behaviour of the driver is not considered at all when giving the cue.

Karlsson (2005) used the remote eye tracking system (Smart Eye Pro Automotive 2.1) developed by SmartEye (www.smarteye.se) in order to determine the drivers' gaze direction. The participants in his simulator study were distracted with an IVIS surrogate that was developed within the European project HASTE. When the participant had looked away from the road, including the speedometer, for three seconds in one single glance, one of two countermeasures was activated. One was a visual stimulus composed of twelve blue diodes whose reflections were visible on the windshield at approximately road centre position. The diodes blinked until the participant looked up or until 1.4 s had passed. This countermeasure can be considered a non-driving related strategy with low automation. The other countermeasure was a single brake pulse which looked like a deceleration of 2.5 m/s^2 during 2 s in the visual representation of the scene. The deceleration that could be felt via the motion system was smaller due to technical limitations. This countermeasure is a combination of a non-driving related strategy at a low level of automation and a driving related strategy at a high level of automation, because its purpose is to inform the driver about his being distracted, but at the same time the vehicle speed is reduced, which could be seen as a preventive measure. The design was within subjects and included two HMI conditions and one control condition. Karlsson did not find any differences in glance duration, reaction time and other driving related measures between the conditions.

Donmez et al. (2007) used visual countermeasures according to a non-driving related strategy with low level of automation in a simulator experiment, in which the participants were distracted with a visual task. The countermeasure had two stages which were activated at different distraction levels (for an explanation of the algorithm see page 44 in this report). Two locations of the countermeasure were compared. The visual warning could either be activated on the screen where the distraction task was displayed or with help of a LED strip on the dashboard. The first warning was a yellow bar telling the driver that he was distracted. When the driver did not look back to the road, the yellow bar was extended with an orange bar on either side. The design was within subjects for the factor feedback with four conditions (two locations, one control without distraction task, one control with distraction task). Generally it was found that distraction had a detrimental effect on driving performance. Regardless of location, the countermeasure led to fewer glances to the display and longer glances at the road. Glance duration to the displays was not shortened by the countermeasures, however, but not extended either. No increase in performance was found for braking or steering behaviour. This was attributed to the low driving demand of the situation. The drivers generally perceived feedback to be of use.

Donmez et al. (2004a) report further experiments in which the drivers were either advised to discontinue the non-driving related task, or in which the screen displaying the secondary task was locked out completely. In the first case a red bezel was displayed around the screen, but interaction was still possible. In the second case the participant had no possibility to continue interaction with the IVIS task on the screen. The activation of the distraction mitigation system did not depend on the driver's glance behaviour, but on environmental conditions, namely a braking of the lead vehicle or a curve entry. A similar setup with an auditory distraction task and an auditory distraction mitigation strategy was tested, too. Instead of the red bezel a clicking noise (1 Hz) was produced for the advising condition. The IVIS task could still be performed. For the lockout condition the clicking noise was present and the task was locked out. No eye glance parameters were measured in the study. It was found that distraction generally had detrimental effects on driving performance. The effects for the visual and the auditory task did not always go in the same direction. While performing the visual task the participants decreased their speed, but increased it while performing the auditory task, for example.

8 Discussion

Until recently there has not been a widely agreed-on definition of driver distraction, rather, there have been some substantial differences between different definitions. The main difference is whether the so-called “cognitive inattention” was included in the definition or not. Distraction has also been defined from different viewpoints. One idea was to investigate what the driver does, he might for example look away, eat something, change a CD or place a phone call. These are observable actions that are easily operationalised, which is an important aspect for experimental studies. In order to diagnose cognitive distraction, one has to make conclusions based on observable behaviour, which requires on step further, since cognitive distraction per se is not observable. The same is true for the notion to define distraction by its effect on the driver’s situation awareness or workload or similar concepts. Those cannot be directly observed, such that, in practice, one has to base one’s judgement on observable behaviour anyway. Therefore it seems more parsimonious to use a definition that can be operationalised easily.

Definitions that are oriented at how driver performance is influenced can be criticised on the grounds that there are indications that distraction does not need to lead to decreased performance at all, or that it can lead to latent problems which might influence performance at a later stage. It does not appear easy, either, to link a certain performance decrement to distraction exclusively and to be sure that it does not come from drowsiness or intoxication or other impairments. Even though the “behavioural interference” definition is easily operationalisable it misses the more cognitive aspects that most likely are at least part of what should be called distraction. This can be seen in many discussions as to whether it is safer to use a handsfree telephone compared to a handheld phone while driving. The advocates for handsfree often assume that the criticality lies in holding the phone and still being able to operate the controls, while the true challenge most often is the conversation that distracts the driver.

Obviously it is not easy to come up with a good and sound definition of distraction that is both well-founded in theory and applicable empirically. An attempt was made at the First International Conference on Distracted Driving in Toronto, however. Still, a few concerns remain. In the proposed definition that was agreed on at the conference it is stated that there has to be a trigger that ”pulls away” the attention from the driving task. It is not stated clearly, however, whether this trigger can be internal or not, but for practical reasons it seems sensible to assume that the trigger has to be external. This simplifies validation, even though a valid indicator of cognitive inattention would be a useful asset, too. Especially in terms of consequences for traffic safety it seems important to be able to diagnose an attention impairment in a driver that is detrimental to traffic safety regardless of whether it is induced by an external or an internal stimulus, and whether the driver looks away from the road or stares blankly at the road. An important asset of the proposed definition is the fact that long-term impairments are specifically excluded. Thus, a clear distinction is made between distraction, which is considered to be short-term and quickly reversible, and impairments like fatigue, alcohol intoxication, diseases etc.

Also, the wording concerned with the consequences related to distraction can be considered slightly unfortunate. An “increased risk of corrective actions” can be interpreted as if it were better not to execute the corrective action at all. Even though this can be deemed a sophistry it could be advantageous to clarify that what is meant is: “an increased probability of getting into situations which necessitate corrective actions,

…”. The idea behind this part of the definition is important, however, because not every distraction needs to have safety-related consequences.

It makes sense to exclude those concepts from distraction, because otherwise the concept of distraction would become too all-encompassing. Excluding them does not necessarily mean that they should be completely unrelated to distraction. It is very well possible that drowsiness increases the likelihood for being distracted, but the two should not be considered to belong under the same concept. Something that clearly distinguishes distraction from the impairments mentioned above is the quick reversibility. Whether a driver is distracted now or not does not allow conclusions about whether he is going to be distracted one minute from now.

Even though it appears to be easier to measure a glance away from the road than cognitive inattention, Victor (2005) proposed a measure for the latter, too, which can be seen as an indicator for “tunnel vision”, that is, a reduced scanning of the areas that do not lie straight ahead. Furthermore, even if it is certain that the driver’s visual focus is not directed at the road, it is still possible to navigate with some precision by using peripheral vision only, as was shown by Lamble, Laakso and Summala (1999) for example. Therefore it can be rather complicated to ascertain whether a driver really was distracted from driving or not, no matter where his gaze is directed. Real-time eye tracking with remote systems is a relatively new technical achievement, and therefore the number of studies conducted is still limited. Most of the studies in which remote eye trackers were used have so far been carried out in driving simulators under controlled conditions. Generally it was found that certain personal features like the presence of facial hair, ears covered by hair, heavy makeup, eyeglasses with reflecting lenses or a dark and heavy frame are detrimental for the quality of the eye tracking data. Additionally, for some systems a rather frequent recalibration is required, which can be cumbersome especially with regard to prolonged field trials. It is expected, however, that the growing interest in remote eye tracking systems both for research and commercial use will lead to a rapid improvement in the systems.

Real-time eye tracking allows the use of glance behaviour as a criterion for distraction. Different zones can be pre-defined as relevant for driving, while others are considered not relevant for driving. It is also possible to set conditions based on which certain zones can be considered as relevant for driving, the side window might for example only be considered relevant for driving when the direction indicator is activated. In this manner algorithms can be developed that should recognise when a driver is distracted. Most of these algorithms are still under development, and they remain to be tested under naturalistic conditions.

As mentioned, most studies concerned with driver distraction have been carried out either in simulators or under relatively controlled conditions on test tracks or, in some cases, in the field. In almost all of those studies distraction was induced in some way by the experimenter, often by letting the participant perform a secondary task. These tasks can correspond more or less to what drivers might do in real traffic, like use the cell phone, enter an address in the navigation system, plan a route on a map versus memorising and adding numbers, checking for matching words or being temporarily blinded by occlusion goggles. The tasks can be visual or auditory, they can be simple or complicated, and they can require immediate attention or leave the driver some leeway in deciding when to attend to the task. The time needed to complete the task can vary considerably, and it can be more or less easy to resume the task after an interruption. Even though these tasks can vary a lot, they are all considered to distract the driver. It is implied that the resources that the driver can use for the driving task are diminished by the additional tasks, which will lead to decreased driving performance.

It is interesting, however, to discuss this assumption with the model proposed by the SAVE-IT team (see Figure 2) in mind. The model implies that in traffic situations that put only low demands on the driver, there should be enough attentional resources that allow the driver to perform a secondary task without having to draw on recources that should be allocated to the driving task. In these situations driving performance should not decrease, even though the driver takes on an additional task. Further, the model indicates that certain impairments might lead to a shrinkage of available resources which do not even permit a satisfactory performance of the driving task without any additional tasks imposed. It might be speculated whether a conscious effort might temporarily increase available resources, such that a participant in a study, who knows that he is being monitored, and who wants to leave a good impression as a driver during the short duration of the study, gives his best and manages to perform quite well on both the driving task and the secondary task, even though he is pressed to the limits. Under conditions like those it might be argued that it is not justified to talk about distraction, but rather about dual task performance. The difference is that the driver is well aware of the fact that he has to perform a secondary task which will be detrimental to his driving. He therefore tries to arrange the two tasks as best he can, and he operates at full attentional levels.

On the contrary a truly distracted driver is not aware of his attention’s being “pulled away” from the driving task. This happens involuntarily, regardless of whether the moment is opportune or not. Of course, the distinction between “true distraction” and “secondary task performance” is not always completely clear and easy. It is possible, for example, that a driver decides to change the CD, and he waits for a suitable moment with low traffic demands to perform this secondary task. He then voluntarily directs his attention to the CD, but inadvertently drops the disk on the floor. It can be argued that the secondary task, which was initiated voluntarily, has an unexpected outcome. Even though the driver still can pace the task of retrieving the disk from the floor, he might become absorbed by this unanticipated turn of events and, thus, truly distracted from the driving task. Many similar examples could be drawn up where a planned non-driving related action turns into “true distraction”.

It has been shown that drivers are often able to predict quite well how traffic is going to develop in the next seconds, at least when other road users follow the traffic regulations (Vogel, Kircher, Alm, & Nilsson, 2003), therefore they should be able to look away from the road after making sure that it is safe to do so and still remain “in the loop” for a short while. The more important to the driver, the more time critical and event paced the secondary task is, the higher the chances that the driver might neglect the driving task even though he should not.

The concept of driving-related inattention, and whether it should be subsumed under distraction or not, is also worth a discussion. Should somebody looking into a mirror or at the speedometer while crashing into a car in front of him, be considered distracted? In this case it seems easy to say that this driver was distracted from the forward roadway. Would the same behaviour be considered a distraction, however, if no crash had occurred? Most likely not, because then every glance at the mirror or the speedometer would need to be considered a distraction, which is not appropriate, because it is well known that most of the times driving safety is improved when the mirrors and the speedometer are used. One way that does not categorically exclude all glances to driving-relevant objects from distraction would be to classify only extended glances at those objects as distraction. A certain percentile of the gaze duration distribution measured for each such object could be used as cutoff point for distraction. Thus, a glance to the mirror that lasts not longer than, say, one second would be considered relevant for driving, but a longer glance would be seen as distraction.

Only few countermeasures that were directed at distraction mitigation itself have been tested so far. Most of them either advise the drivers to look back at the road or interrupt the driver's interaction with the secondary task. Even though there are indications that the drivers judge the feedback to be of use, it has to be considered that the drivers were exposed to the countermeasure for only a limited period of time in a rather artificial setting. There have been indications that initial enthusiasm for a countermeasure can turn into dislike if the warning is experienced to be annoying over time, or is giving too many false alarms (Ervin et al., 2005a). Therefore it is important to test a mitigation system over a prolonged period of time in order to get more reflected acceptance ratings that are based on experiences during everyday driving. Under more naturalistic conditions it is also possible to test whether a dedicated distraction countermeasure really helps or rather leads to further distraction. In this case it might be advisable to focus more on the adaptation of other warnings depending on driver state.

The reviewed literature and the discussion above show that in order to collect data on natural distraction, it seems necessary to conduct a field study without any experimenters present in the car. The driver should be given enough time to get used to the vehicle (in case they are not driving their own vehicle), to the equipment, and to "forget" or ignore the fact that they are being observed by instruments. It is also important that drivers behave as they usually do, without artificially imposed tasks and without driving preselected routes. This implies that the study has to be long-term, and the drivers should go about their daily routines and drive as they normally do. The recording equipment should be discreet, such that the drivers are not reminded that they are being observed, and there should not be too much contact with the participants during the field trial from the experimenter's side, in order to keep the driving situation as normal as possible. Past studies have shown that drivers start to behave naturally quite fast, judging from their tendency to commit violations and to exhibit other not socially desirable behaviour. This method is obviously costly, because it takes a lot of time and resources, and additionally there is no guarantee how much useful data will be obtained. The collected data will, however, be valid for real world driving, and with their help a validation of simulator data is possible.

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POST/MAIL SE-581 95 LINKÖPING
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POST/MAIL BOX 760
SE-781 27 BORLÄNGE
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