Evaluating Driver Distraction Countermeasures

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Abstract

Statistics showing that in-vehicle driver distraction is a major contributing cause in road accidents is presented. Driver distraction is defined building on the driving theory by Gibson and Crooks. The idea to use driver distraction countermeasures as a way of mitigating the effects of the driver distraction problem is then introduced. A requirement list is formulated with ten requirements that distraction countermeasures should meet. A simplification of regarding distraction as a gaze direction problem makes way for designing an experiment to evaluate two driver distraction countermeasures in which new eye-tracking technology plays a key role. The experiment also makes use of a simulator, a surrogate in-vehicle information system as a distractor, and thirty subjects. The most important dependent measures were in-vehicle glance time and a steering wheel reaction time measure. The evaluated countermeasures – a blue flash at middle of the road position and a kinesthetic brake pulse – could, however, not be shown to meet the most important of the requirements formulated. The lack of effect of the countermeasures in the experiment may either depend on their actual inefficiency or on methodological shortcomings of the experiment. These alternatives are discussed. It is speculated that the biggest problems with the possible lack of actual efficiency have to do with that the theoretical basis for using a flash did not transfer to the driving setting, and that the brake pulse used was too weak. The methodological problems have to do with the non-validated dependent measures used, missing data, nuisance warnings, insufficient distractors, non-precise hypotheses, and difficulties with separating the effect of the countermeasures from the psychological force to look on the road.

Keywords: Driving Behavior, Accident Prevention, Attention, Distraction, Simulators, Eye Movements
Preface

This master thesis has been written as a part of the studies at the cognitive science program in Linköping, Sweden. The thesis has also been a part of a joint venture with the Swedish National Road and Transportation Institute (VTI), SAAB Automobile AB and SmartEye AB. The project was funded by SAAB Automobile and Vinnova. The purpose of the project was to contribute with knowledge about and develop driver distraction countermeasure(s) that redirects the gaze of a visually distracted driver to the road in order to increase traffic safety.

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Introduction

There has always been a concern for how new technology can lead to drivers that do not focus on the road. Around 1915 the concern was about how windshield wipers might cause drivers to be distracted or hypnotize them by their repetitive monotonic motion. Later, in the 1930:s when radios were introduced in cars some states in the US considered to ban them because of their alleged distractibility (GM, 2003). Today we see a proliferation of in-vehicle information systems (IVIS) such as telephones, navigation systems, email, Internet services and even television in cars and an accompanying concern for their distractibility.

Recent statistics material suggests that this concern is justified as will be shown below. It is shown that in-vehicle distractors constitute the largest source of driver distraction. This concern leads car manufacturers to engage in research to come up with new knowledge about driver distraction and technology that can mitigate the hazardous effects of new (and old) IVIS. One way to do this is to develop driver distraction countermeasures. Driver distraction countermeasure ideas are becoming extra interesting because of the unobtrusive eye-tracking technology that just recently have entered the market. This thesis is one of the first academic works that uses unobtrusive eye-tracking technology to evaluate driver distraction countermeasures and it has therefore been of an explorative nature when it comes to methodology and technology. The aim has, however, been to contribute with knowledge so that future research may be facilitated.

The epidemiology of driver distraction

Road accidents that lead to fatalities and injuries are a global health concern (Peden, 2001). To find out exactly how big the problem is, is not easy, but some sources claim that about 3,000 people are killed and 30,000 are wounded every day on the world’s roads (Norton, Hyder, & Peden, 2001; Roberts, Mohan, & Abbasi, 2002). The concern for traffic safety is thus justified. In Sweden, where 551 people were killed and 22,913 were injured during 2001 (SIKA/SCB, 2002), this concern is manifest in the radical governmental policy of the Vision Zero program (SNRA, 2003), with the goal to reduce fatalities and serious injuries in traffic to nothing. This policy has led to big efforts in infrastructure development, but the policy also puts demands on traffic research to explore every possible cause of traffic accidents. Here, the focus will be on one of these possible causes; driver distraction, and especially on in-vehicle distraction. Before a presentation is made of available statistics on driver distraction just a few things should be mentioned about accident causation.

To establish the cause of an automobile accident is difficult. It is never only one particular event that causes an effect. It is always a complex of conditions that lead up to an effect, and to complicate it further, this complex can be different every time it causes the effect. This is basically what Mackie (1965) means with his causation theory in which he introduces the notion of the INUS condition (an Insufficient but Necessary part of a condition that in itself is Unnecessary but Sufficient for the result). The following fictional yet illustrative short story could serve as an example: “A young driver is in a hurry to get to his girlfriend’s house, and is driving at 80 mph on a 65 mph road just after a rainstorm has passed. He is
also busy operating his newly installed radio. Suddenly, a deer comes up from the left ditch of the road. When our driver sees the deer he steers the car off the road, hits a tree, and is fatally wounded.” Is it because he is speeding, or because the road is wet, or because there are trees beside the road, or because he is operating the radio, or because the radio has a strange user interface design, or because the radio is located far from the steering wheel, or because the driver is young and inexperienced, or because he is a man, or is it just because he is driving a car, that the young man dies in this example? Of course, all these conditions (and many more) taken together could be said to cause the result of the tragic story. That the driver was distracted by the radio is an insufficient, but as we look upon it in driver inattention and distraction research, a necessary or at least contributing condition for the driver to hit the tree. Taken together with other conditions the whole is sufficient to the result of the accident. There are many other conditions that have to be fulfilled for there to be an accident, the distraction by itself is not enough. Nevertheless, to get anywhere in a research attempt to increase traffic safety we have to delimit the problem and disregard some conditions and look on one recurring condition, which we think is highly relevant. In this thesis it is the contributing condition that in-vehicle distraction means that will be under consideration.

It is not easy to find out how many accidents that involve in-vehicle distraction. Indeed, it is generally very difficult to establish the different conditions of accidents that have to do with pre-crash driver behavior. If asked about what was going on before an accident, the driver might have forgotten, does not want to tell, or is unable to express her attentional state prior to the accident. Wang, Knipling, & Goodman (1996) put it like this: “Crash investigation is inherently a retrospective, reconstruction process rather than an empirical process. There are no “instant replays.” Therefore, even the best and most in-depth crash investigations are, to some extent conjectural.” (pp. 14-15).

A number that is often mentioned in the literature is that 25% of crashes depends on driver distraction/inattentiveness. This figure probably has “its roots” in a study carried out by Wang et al. (1996) which states that 25.6% of the towaway crashes of 1995 in the US involved inattentive drivers with 13.2% specifically involving distraction. This figure is based on the same CDS data that Stutts, Reinfurt, Staplin, & Rodgman (2001) used in a more recent study. In this later study, Stutts et al. report that 8.3% of the total number of accidents involving at least one passenger vehicle that was towed away from the crash scene, had drivers categorized as distracted. This statistic is based on the US National Accident Sampling System (NASS) Crashworthiness Data System (CDS) for the years between 1995 and 1999 (i.e. not only 1995). Professional field researchers that have been trained to fill out a form with predefined categories, gather information from a sample of accidents. The sample consists of approximately 5,000 police-reported crashes annually and is weighted to reflect the total number of US towaway crashes. Most of the information that is collected in each investigation deals with, as the database name suggests, how the crashed cars physically managed the accident, but since 1995 the form also has a special section devoted to driver inattention and distraction. In this way it may be possible to make approximate inferences about the overall incident rate of driver distraction related accidents. To see how Stutts et al. speak about the distraction definition see the next section on the distraction concept (p. 5).
Out of an average total number of 3,420,000 drivers in US towaway crashes per year during 1995-99, 284,000 (the 8.3%) were distracted according to the CDS protocol. Of these drivers, 7.9% were seriously or fatally injured which translates into approximately 22,400 people. Stutts et al. (2001) further divide the distracted driver category into different types of distraction sources: “Outside person, object or event” - 29.4%, “Adjusting radio, cassette, CD” - 11.4%, “Other occupant in vehicle” - 10.9%, “Moving object in vehicle” - 4.3%, “Other device/object brought into vehicle” - 2.9%, “Adjusting vehicle/climate controls” 2.8%, “Eating or drinking” - 1.7%, “Using/dialing cell phone” 1.5%, “Smoking related” 0.9%, “Other distraction” - 25.6%, “Unknown distraction” - 8.6%. Note that 37% of all the distraction can be classified as in-vehicle distraction (see Figure 1).

There is more research that support the Stutts et al. (2001) result that a large part of what is classified as distraction related crashes involves in-vehicle distraction. An accident narratives data base was searched using keywords by Wierwille & Tijerina (1996) with North Carolina data from 1989 and 1992. Of 189,464 narratives 2,816 (1.5% of all narratives) were relevant citations, i.e. narratives that really had to do with distraction. Of these relevant citations, 55% of all the distraction can be classified as in-vehicle distraction. In an Australian study with statistics from New South Wales, presented by Lam (2002), it is shown that all age groups except 40-49 year olds are at greater risk to be involved in an inside-vehicle distraction related crash than they are to be involved in a no distraction related crash. The risk of being involved in an outside vehicle distraction crash was less than both inside-vehicle distraction crash and no distraction crash.

All of the presented statistics have clear weaknesses. The NASS/CDS numbers must be considered in light of the fact that of the total number of estimated US towaway crashes, 35.9% of the involved vehicles had drivers whose attentional state was categorized as unknown. This is a very large number, making the other
numbers unreliable. However there are reasons to believe that the problem is not that too many accidents are reported as involving distraction, rather the problem seems to be that of underreporting. Of the 48.6% that were reported as attentive in the Stutts et al. study one might suspect that some were maybe not attentive after all. Wang et al. (1996) made the interesting observation that in their 1995 data, 45.8% of the drivers who were categorized as attentive did not attempt an avoidance maneuver, which, as they put it, “...is somewhat surprising in view of the what would be expected from an attentive driver.” (p. 13). For the narratives study, the problem of underreporting is even worse. With open-ended narratives it is even more uncertain that distraction cases are captured. Some distraction sources are perhaps easier to write about in the police reports while others do not get any attention at all from the police officers. More important, however, is probably road users’ unwillingness to report their own negligence or carelessness, as they might feel a lapse in attention is. Exactly how prevalent driver distraction is as a contributing factor for accidents is difficult to say, nonetheless, it is vital to recognize that driver distraction is an important contributing factor in road traffic accidents. Indeed, despite all the weaknesses in the statistics material presented above, it is clear that different types of unsafe driver distraction do exist, and different studies suggest that in-vehicle distraction seems to constitute a substantial portion of the total driver distraction problem.

The driver distraction concept
We have now seen that many accidents on public roads could be partly attributable to driver distraction, but what does the driver distraction concept mean? That is the question for this section to answer. The first step will, however, not be to plunge into a discussion of distraction, because first it is vital to have a grasp of what safe driving is about.

Driving
The primary driving task is a human factors concept that is widely used to denote what driving is from a safety point of view. A problem with the concept, however, is that it is often only loosely referred to as something the driver should be occupied with in contrast to secondary tasks, such as talking on the phone, using the navigation system, or tending a baby. Another problem is that to speak of one primary task might be misleading since some authors speak about several driving tasks. Here a complete presentation of all the subtasks in driving will not be presented, since the objective of this thesis is different. Presentations in a thorough style of driving tasks have been made elsewhere (McKnight & Adams, 1970; Michon, 1985). The matter of interest here is only to have some form of theoretical framework that provides a conception of the primary driving task(s) at a proper level of detail. To serve our purposes, this framework should also account for the driver distraction concept. The analysis of Gibson & Crooks in their paper from 1938 (Gibson & Crooks, 1938) may be such a theoretical framework with a useful level of detail. Somewhat simplified, the goal of safe driving, and hence the primary driving task, is to always be able to steer or stop so that collisions are avoided. Gibson & Crooks call their study a “Theoretical field-analysis of automobile-driving” in which a whole set of concepts to describe driving is presented. In this set the concept of ‘field of safe travel’ takes a central position. The field of safe travel is in the direction where the car is headed and bounded laterally by meeting traffic, ditches and pavements, etc. and frontally by traffic in
front of the car. The boundaries of this field are thus made up of obstacles, which
the driver must avoid. In the field analysis there is also another field or zone that
is called the ‘minimum stopping zone’ which is bounded by the distance that is
required to come to full stop from the current position and speed if maximum
braking is applied. When the field of safe travel shrinks so that it frontally
becomes nearly as small as the minimum stopping zone, the driver becomes
uneasy and adapts by reducing speed to increase the safety margin (difference
between field of safe travel and minimum stopping zone). If the field of safe travel
becomes smaller than the minimum stopping zone, the driver is in an emergency
situation. In the terms of Gibson & Crooks, the task of the driver is thus to keep
the ratio between the field of safe travel and the minimum stopping zone, the
field-zone ratio, of a proper magnitude. Their hypothesis is that this is mainly a
perceptual task and that the steering task “is a perceptually governed series of
reactions by the driver of such sort as to keep the car headed into the middle of the
field of safe travel” (p. 456). Braking and accelerating are also in the same manner
‘governed’ by perception. It is by perceiving and attending to the road that the
tasks of driving may be properly accomplished. In the terms of Gibson and Crooks
there is actually one predominant driving task and that is to maintain a visual
field1 so that the field of safe driving and the minimum stopping zone are correctly
bounded. This is also how the primary driving task is defined in this thesis.

Distraction

When the driver’s visual field is not properly maintained, because of the driver’s
visual engagement into non-driving related events, a mismatch between the
behavioral field of safe travel and the objective field of safe travel might be the
result. Gibson & Crooks (ibid.) phrase it like this:

Inattentiveness in the driver usually means that
objects in the terrain or inside the car which are
not pertinent to locomotion stand out in his visual
field and that consequently his field of safe travel,
if it exists at all, may become incorrectly bounded.
(p. 458)

This definition of inattentiveness is very close to what is meant by distraction in
this thesis. It should only be complemented with two details to work as this thesis’
distraction definition. The first is that there is a time aspect involved in
distraction; it is only after some time has passed of engagement into things not
pertinent to safe driving that the field of safe travel may become incorrectly
bounded. The second is that the non-pertinent objects must be external to the
driver. These two details are emphasized in a much more recent driver distraction
definition provided by Stutts et al. (2001):

AAAFTS2 has chosen to focus its efforts specifically
on driver distraction, rather than the broader
category of driver inattention. It defines distraction
as “when a driver is delayed in the recognition of

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1 Gibson & Crooks (ibid.) use the visual field concept to denote the awareness of the driving situation
that the driver has acquired through perception and attention. We will later call this ‘recognition of
information’.

2 American Automotive Association Foundation for Traffic Safety
information needed to safely accomplish the driving task because some event, activity, object, or person within or outside the vehicle compelled or tended to induce the driver's shifting attention away from the driving task. The presence of a triggering event distinguishes a distracted driver from one who is simply inattentive or “lost in thought”. (p. 6)

Here, a triggering event, activity, object, or person in the driver's environment will also be called a distractor.

The first thing we notice with this distraction definition is that, a “delay in the recognition of information” is needed for a person to be considered as distracted. That is, the time during which the visual field of the driver is not updated, in order to correctly bound the field of safe travel and the minimum stopping zone, is what turns a driver into a distracted driver. If it is enough for this delay to be only slightly above 0 s for a driver to be distracted or whether the delay must be longer is something that is not discussed by Stutts et al. (ibid.). We will, however, return to this issue in the discussion of a distraction criterion below (p. 14). It is also worth notice that to define distraction along the lines of recognition delay also means that a total failure of the primary driving task, e.g. driving off the road, is not needed for a person to be called distracted.

The second observation we may make of this definition is that the distractor must be external to the driver. An inattention source from 'within' the driver is not a distractor which means that a driver who is simply inattentive or 'lost in thought' is not distracted. Neither are states like drowsiness, preoccupation with competing thoughts, daydreaming, worrying, being caught in affection, etc. regarded as cases of distraction. This is contrary to many other definitions of attention and distraction. William James states, e.g. that “[attention] is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called distraction, and Zerstreuheit in German.” (James, 1890/1981, p. 382). The “confused, scatterbrained state” is something that! stutts et al. would call inattention and not distraction. Using this definition of driver distraction means that there must always be a distractor in the driver's environment that causes a shift of attention away from the primary driving task. That the attention is directed away from the primary driving task is invariably the effect of the distractor. Another way to say this is that the driver will become distracted if and only if there is a distractor present in the driver's environment.

The inattentiveness definition of Gibson & Crooks and the driver distraction definition of Stutts et al. taken together show to be a fruitful combination. The Gibson & Crooks definition relates our issue to a comprehensive driving theory and the Stutts et al. definition introduces the time aspect and makes a distinction between inattention and distraction by saying that distraction is the result of triggering events external to the driver. The distraction definition of this thesis is therefore: Distraction occurs when a driver is delayed in the recognition of information needed to accurately bound the field of safe travel and the minimum

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5 Distractor rather than distracter since the latter is more a person and the former could be anything, a general event.
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.

The discussion up to this point helps in defining what a driver distraction countermeasure is. A driver distraction countermeasure redirects the attention of a distracted driver from the distractor to information that is necessary to bound the field of safe travel and the minimum stopping zone.

Some remarks and a simplification

DRIVING AND MOTOR FUNCTIONS
According to our definition, distraction affects driving in a negative manner primarily at a perceptual level (“recognition of information”). The definition implies that motor functions are not directly impaired by distraction. However, impairment of perception usually leads to improper motor responses and these improper motor responses are, indeed, the unwanted unsafe behavior that leads to accidents. Nevertheless, here we have the belief that these motor responses are perceptually governed, and therefore it is the perceptual aspect of the problem that should be in focus.

THE CONTEXTUAL DEPENDENCY OF DISTRACTION
Whether an event is categorized as a distractor is dependent on the driver and the situation. Something that is distracting to one person at one time is perhaps not distracting to another person (or the same person) at another time. We will return to this discussion when we speak about experiment distractors (p. 18).

A SIMPLIFICATION: ATTENTION AS GAZE DIRECTION AND A DISTINCTION TO LOOK BUT DID NOT SEE
In our distraction definition the attention shift away from the pertinent information is central. Changing gaze direction is often linked to such an attentional shift. Theoretically, it is however possible to direct attention to different parts of the field of view. However, since the fovea is only 2 degrees of visual angle, gaze is for much of the time driven by our need to attend (Wickens & Hollands, 2000). That is, to attend to different things while driving, gaze has to be redirected most of the time.

Sometimes it is, however, not enough to gaze on something in order to pay attention to it. The “looked but did not see”-phenomenon means that the driver directs the gaze on something without it being included, as it should have been, in the visual field of driving. When an obstacle or a hindrance in front of a driver’s own car is run into, although the driver is looking at it, then we have an example of “looking without seeing”. The “looked but did not see”-phenomenon can for instance be studied in change blindness experiments, (see e.g. Rensink, 2000) and is also one of the inattention categories of the NASS/CDS statistics (see p. 3). However, the driver distraction concept does not involve the “looked but did not see”-concept.

In other words, there are two relevant aspects of a driver’s attention. The first aspect is that the driver must direct the gaze on pertinent information for locomotion. If the driver does not, s/he is distracted (by an external object) or inattentive (by an internal state). The second aspect of the attention problem of
driving is that it is not enough to direct the gaze; the driver might despite the fact
s/he is looking at the road not be attending to pertinent traffic events, and then
s/he is looking without seeing. Thus, whereas the “looked but did not see”-
phenomenon might be seen as a cognitive attention problem, driver distraction
might be seen as a gaze direction problem. Since the focus of this thesis is on
driver distraction, it is gaze direction that will be studied here, whereas the
cognitive aspects of attention that the “look but did not see”-phenomenon
highlights will be disregarded for the time being.

With the simplification of equating attention with gaze direction and disregarding
the “looked but did not see”-phenomenon we may rephrase our previous
definitions:

**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 gaze away from this information.**

**A driver distraction countermeasure redirects the gaze of a distracted driver from
the distractor to information that is necessary to bound the field of safe travel and
the minimum stopping zone.**

**Understanding the distracted driver**

Behind the numbers that were presented in the statistics section above (p. 1) are
many individual cases where one or more drivers were distracted. To better
understand the distraction problem, this section will first present an individual
case of driver distraction taken from real life that led to an accident. Then the
psychological force that does not suffice when drivers are involved in distraction
accidents is discussed. This section ends with a presentation of a theory that may
help to explain what happens when a driver is distracted.

**An individual case**

A fictitious story was told above (p. 1) about a young driver on the way to his
girlfriend’s house – this is one example of an individual case, but it would be much
more interesting to have accounts of real accidents. However, it is often considered
as bad ethical practice to publicize real-life accident reports. The Swedish
National Road Administration regards their accident reports as highly sensitive
personal information and do not allow their reports to be made public so that
individuals’ identity could be revealed (SNRA, 2002). The American National
Transportation Safety Board does, on the other hand, make accident reports
available on the WWW. Here follows an excerpt from an accident report involving
a truck-driver, a clipboard, and a school bus.

**Injuries**

2 serious, 33 minor injuries

**Accident Description**

The truckdriver stated that he was traveling east
on U.S. Highway 290 about 56 mph when he struck
a stopped school bus on Nicholson Lake Road. (See
figure 1.) The truckdriver said that prior to the
collision he braked and swerved to the left, but the right front of the truck struck the left rear of the school bus. Two students sustained serious injuries; 31 students, the busdriver, and the truckdriver sustained minor injuries. Both vehicles were destroyed.

The truckdriver stated that he did not see the school bus because he was late and had been looking on his clipboard for a telephone number to call a business. He found the telephone number and was placing his clipboard between the seats when he looked up and saw that the school bus was stopped. He had been awake for 14 1/2 hours and, except for a 45-minute nap, had been on duty for 13 1/4 hours and had been driving for almost 10 hours. By the time the driver would have completed his shift, he would have been awake for 18 hours, on duty for 15 hours, and driving for 12 hours. When asked how he felt, the driver stated that he was "physically tired" but believed that he was mentally alert.

**Probable Cause**

The National Transportation Safety Board determines that the probable cause of the accident was the truckdriver's inattention to driving. Contributing to the accident may have been the truckdriver's fatigue.

(NTSB, 2002)

In this accident we see that it is perhaps not only distraction that causes the accident. The driver, although stating otherwise, might have been drowsy as well, but distraction is one of the contributing factors. In this accident it was attending an in-vehicle clipboard that made the driver look away for too long for the situation at hand.

**The psychological force to look on the road**

Despite the story just told it is most natural for drivers to attend to the road, otherwise we would have had many, many more accidents\(^4\). To be sure, if deprived of the visual field the driver soon becomes very uncomfortable. In fact there seems to be a psychological force not allowing for long glance times off the road. In a review by Green (1999), results from an experiment (Hada, 1994) that had American subjects that drove on a real road and were asked to look away from the road as long as they felt safe to do so, are reported. Below are the results from that experiment.

\(^4\) Automobile driving would probably not have been a human activity at all.
Introduction

Figure 2: Glance duration histogram of Hada (1994)

The median glance times inside the vehicle were 0.86 s on the expressway, 0.81 s on the rural road, 0.68 s on the suburban street, 0.79 s on the urban street, and 0.87 s while stopped at urban intersections. Less than 5% of the totally 10,660 glances were longer than 2.2 s (95\textsuperscript{th} percentile). The 97.5\textsuperscript{th} percentile was 2.5 s and the 99\textsuperscript{th} percentile was 3.6 s. Another similar study (Kimura, Osumi, & Nagai, 1990) with Japanese subjects that got the instruction to look at in-vehicle targets “for as long as possible until you feel uncomfortable”, reported average glance times that were much higher with medians up to 2.0 s. In another review, this time by Wierwille (1993) that focuses on natural glance behavior (with no instructions) for in-car controls and displays, results show that single glance times fall into a relatively narrow range and it is the number of glances that vary with in-car task difficulty. The conclusion that Wierwille draws is that drivers usually do not, on the average, look into the car for longer than 1.6 s at the time.

The psychological force to look on the road has also been empirically investigated, albeit a little differently, by Senders et al. (1967). These authors argue for a psychological speed limit that is related to the amount of visual information a driver is allowed to receive. In their study it was shown that intermittently occluding a driver’s line of vision so that the driver cannot see the road, makes the driver slow down.

These studies suggest that drivers have a “psychological force” to look at the road. The reason for this has probably to do with that people are instinctively concerned about their safety. In fact, it could be argued that it is surprising how reliable this instinct is. Nevertheless, all too many accidents occur and the important question arises “What cancels the psychological force to look on the road?”. A tentative answer to that will be discussed now.

Contention scheduling in attention

There was something with the clipboard that made the truck driver look down, so much that the primary driving task was not properly carried out. The psychological force that urges for look out was in this case too weak.

The action theory by Norman and Shallice (Norman & Shallice, 1986) is useful to explain conflicts between tasks. According to their theory, people receive sensory information that goes via sensory-perceptual structures to a trigger database that
has triggers, which triggers schemas that prompt for certain actions. Different schemas can be triggered simultaneously and if they do not compete for action resources, the actions associated with the schemas can be carried out simultaneously. If the schemas do compete for action resources the schema with highest activation value will take over through activation and inhibition in contention scheduling. This process may go on with no conscious or attentional involvement, but through the supervisory attentional system (SAS), will-power and attention can be exerted for activation and inhibition of schemas also. A third factor, which influences schema activation, is motivation that operates parallel with SAS. This theory elegantly accounts for e.g. the cognitive distinction between automatic and controlled processing, the Stroop phenomenon, capture errors, and even neuropsychological evidence.

We may formulate the driver distraction problem in terms of the Norman and Shallice theory. Schemas that are likely to possess higher activation levels than the primary driving task schema are distracting schemas if their gaze action component is put in conflict with the gaze action component of the primary driving task schema. An example of such a conflicting schema is the clipboard operation schema whose gaze action component corresponds to gaze inside the vehicle and is thus in conflict with the gaze action component of the primary driving task. In the case of our truck driver, not enough activation was received by the “primary driving task”-schema so therefore the action component of “reading the clipboard”-schema was carried out, much to the dismay of everyone involved at the scene of the crash.

The countermeasure method to reduce in-vehicle distraction

There are, at least, two possible main paths to reduce the problem of distraction. The first is to reduce the possible hazardous sources of it. The second is to actively try to counteract these sources by other stimuli presented to the driver. The first possible path, which we may call “workload design”, has already been probed by the car manufacturing industry and is manifest in the policies of design of cockpit, IVIS user interfaces, and task management systems and also in some states’ and countries’ law texts. The second possible path, which we may call “attention support” (Victor, 2000), is a comparatively new approach, and is the path that we will follow in this thesis. The idea here is that if driver distraction occurs, in spite of attempts to “build it away”, it would be good to have something that realerts the driver to the road. The advantage with an attention support system in this sense, is that it (at least conceptually) counteracts all possible distraction sources, also those that are not pertaining to IVIS:s, e.g. objects brought into the vehicle such as maps, portable computers, crying babies, food etc. The special form of attention support system that we will study in this thesis is the distraction countermeasure system. Here, a distraction countermeasure system is a system that has a way of monitoring the driver to make inferences about the driver’s attentional status and if a distraction criterion is met it activates some distraction countermeasure.

Previous research

In previous research, distraction countermeasures per se have not been so thoroughly studied. Research on collision avoidance systems has been more
Here, the difference between collision avoidance systems and driver distraction countermeasure systems will be considered as a difference in sensor technology. Collision avoidance systems use vehicle status/environment sensors that estimate headway and time to collision (TTC), whereas distraction countermeasure systems use driver status sensors for instance those that follow eye gaze behavior. Although the sensor technology is different, inspiration for the development of realerting stimuli for a distraction countermeasure system can be drawn from the collision avoidance literature. Two examples of collision avoidance system studies will be presented here, one of which partly is a review. These have been chosen since they both involve distracted drivers.

**Lee, McGehee, Brown, & Reyes (2002)**
In this study different timings of warning set-in were studied in a driving simulator with both distracted and undistracted drivers. The drivers were exposed to imminent rear-end collisions while being distracted and, not surprisingly, it was found that early warnings had better effect, in terms of avoided collisions and decreased impact severity, than had late warnings. The warning that was used was a combined auditory and visual signal. The auditory tone was made up of four sound bursts and each of the bursts had four pulses. The bursts came every 110 ms and the pulses were separated by 10 ms. The visual display was mounted just above the instrument cluster and depicted a vehicle colliding with the rear of another vehicle.

**Shutko (1999)**
In the literature review of Shutko's master thesis, studies of warning signals of collision avoidance systems are presented. A reference to Dingus (1996) is made in which a “soft braking” warning was used. This kind of warning has the advantage that it warns the driver at the same time as the vehicle slows down a little. Furthermore, the operation of “soft braking” has the advantage of being discrete in the sense that passengers of the car cannot know whether it is a warning that sets in or if it is the driver who applies the brakes. In the Dingus study the brake force that was used was 0.2 g and this helped drivers to avoid collisions.

Other sources presented by Shutko come with recommendations about brake pulses. The first of these sources states that a brake pulse should not startle the driver or in other ways disrupt driver performance. Moreover, each brake pulse should be approximately 300 ms. How many pulses or how close in time they should come for each warning set-in seems to be something that is not detailed by this author (Landau, 1995). The second of these sources points out that a brake pulse induces less mental load on the driver, is discrete, and may reduce driver reaction time (Onken, 1994). Finally, there are sources that claim that a brake pulse should be used for forward emergency situations (Weber, Mullins, Schumacher, & Wright, 1994), or as an imminent warning (Wilson, Butler, McGehee, & Dingus, 1996).

Shutko himself used auditory and kinesthetic\(^5\) (brake pulse) warnings in an instrumented commercial truck. The auditory signal was an auditory icon (earcon) that sounded like a tire skid and with speakers located in front of the driver this might be perceived as a vehicle in front that decelerates suddenly and quickly.

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\(^5\) Shutko calls the brake pulse a haptic warning. Here, the term kinesthetic is used instead.
The kinesthetic signal was implemented so that the brakes were pumped for one second with a deceleration of 0.3 g. It was found that the auditory warning decreased movement times of the foot from accelerator to brake pedal while the brake pulse decreased the number of collisions and impact speed.

Countermeasure requirements
We have previously defined what a distraction countermeasure is (p.8); namely that it is a stimulus that redirects the gaze of a distracted driver to the road. There are, however, other surrounding requirements that apply to a distraction countermeasure. During the process of writing this thesis a tentative list of requirements that apply to driver distraction countermeasures has been developed that deals with this problem. Such a list works also as an important guideline for the design of experiments that evaluate countermeasures. The most important aspect that deals with the definition of a driver distraction countermeasure is found at the top of the list.

1. **Direct gaze to the road.** The first requirement is that a countermeasure should get the driver’s eye gaze back to the road.
2. **Enhance ability to cope with critical situation.** The driver should be helped by the countermeasures to e.g. avoid collisions or driving off the road.
3. **Fast.** It should not take long for the countermeasure to have effect after countermeasure onset.
4. **Unambiguous.** The countermeasure stimulus should not be confusing or interpreted by the driver to mean something that it does not mean.
5. **Not distract.** It should not delay the driver further in the recognition of information to bound field and zone (see driver distraction definition p. 5) – only direct the driver’s gaze to the road.
6. **Not occlude.** The physical realization of the countermeasure should not occlude the visual field of the driver.
7. **Not auditive.** Since it is possible to drive (in Sweden) without hearing, the countermeasure should not rely on hearing.
8. **Accepted.** For the countermeasure to be accepted by the driver it should not be experienced as distressing, upsetting or annoying.
9. **Reliable.** A countermeasure should work every time and despite large variations in the ambient environment.
10. **Realizable.** It should be possible to introduce in mass production in cars at a reasonable cost.

The first of these requirements is quite straight forward and follows the definition we have of driver distraction that states that distraction is about gaze direction. The second requirement is an important complement to the first, since it emphasizes the reason why drivers should have their gaze on the road. The third and fourth requirements relate to the desire that the countermeasure should be intuitive and not require high order cognitive processing resources. Exactly how fast the countermeasure should have effect is not detailed here.

The fifth and sixth requirements point out that there is a possibility that, if not properly designed, countermeasures may do more harm than good. The seventh requirement in the list could be discussed since it has been shown that auditory stimuli have effect (Lee et al., 2002; Shutko, 1999) and are usually faster than visual stimuli (Wickens & Hollands, 2000) and in most other research and warning discussions it is taken for granted that the auditory channel might be
used to mediate a warning. In this thesis it is, however, noted that the hearing impaired also may drive so therefore it must be of interest to recognize this fact and come up with countermeasures that also this part of the population may benefit from. The eighth requirement is important since drivers must be willing to use the system, otherwise it is not of much use. The ninth requirement has to do with that whenever and wherever the driver is categorized as distracted, even after many years of use, or with many repeated activations of it, or during any season, or time of day in city or on highway, the countermeasures should still have effect. The last requirement is of a very practical nature, but not of less importance. It is not meaningful to develop countermeasures that cannot be implemented in cars in real life.

Distraction criterion
In the case of collision avoidance systems (CAS) the criterion for warning set in is calculated by using sensor information that estimates distance to the vehicle in front and relative speed of the vehicles. In the distraction countermeasure system of this thesis the sensor information is eye gaze direction and duration. Here a discussion follows of a simple distraction criterion model that only makes use of such eye gaze information. In this discussion, “information needed to accurately bound the field of safe travel and the minimum stopping zone” as our driving task definition and distraction definitions formulate it (see p. 5) has been replaced by “ROAD” for reading comfort. A simple, basic idea is that the longer a driver looks away from the ROAD the more critical it becomes. A distraction criterion for a driver distraction countermeasure system specifies how large this delay can be before a driver is categorized as distracted and thus when a distraction countermeasure should set in.

One could say that the driver has an attentional budget that runs out if the driver looks away from the ROAD too long, and conversely, when the driver looks on the ROAD again the attentional budget receives “funding”. In this model a distraction criterion is set by three parameters. First, by the initial budget limit when nothing has been spent on off-ROAD glance time. Second, by the rate at which the budget runs out when the driver looks away from the ROAD. Third, by the rate at which the driver receives funding when looking up again. If the budget runs out, a warning could possibly set in to counteract the budget deficit. Some would say that the currency of such an attentional budget is information bits (Senders et al., 1967). In a simplified model we could, however, use time units.

To exemplify how it might work, let us assume that the budget is three seconds, i.e. when the driver has looked away from the ROAD for three seconds the system should warn. Let us say that a driver wants to find a particular CD in a pile of CDs on the passenger seat. While driving, s/he looks down on the passenger seat for 2 seconds (Budget: 1s) but does not find it instantly so s/he looks on the ROAD again, but only for a short time, 0.5 s, too short to notice the pedestrian further down the road (Budget: 1.5s). Then s/he looks on the passenger seat again for more than 1.5s and the alarm sets in just in time for our driver to notice the pedestrian, who has staggered out on the road (and thus has become part of the ROAD). Our driver just has time to steer around the pedestrian. Notice that this distraction event is divided into two glances away from the ROAD. Note also that in this example the increment and decrement constants are both set to 1. It is most probable that they should be set to something else. One might speculate that the increment constant should be higher than the decrement constant, i.e. when the
driver looks on the ROAD the number of seconds should multiply with a constant that is more than 1. For instance the increment constant could be 2, then when the driver looks on ROAD for 0.7s the budget is increased with 0.7x2 = 1.4s.

There is one study that has used a variant of this distraction criterion model. In an on-the-road study (Holmström & Johansson, 2003) ten subjects drove for ten minutes in city traffic and ten minutes on suburban road each, with no other tasks. They used the SmartEye eye-tracking equipment (see p. 17) and divided the visual environment of the driver into six zones: primary, windscreen, main instrument unit, left rear mirror, right rear mirror, and inner rear mirror. The different zones had different increment/decrement constants and the constants also depended upon road type. Note that this division implicitly relies on the assumption that chances of recognizing “information needed to bound the field of safe travel and the minimum stopping zone”\(^6\) are highest in the so called primary zone, which was at approximately middle of the road position.

<table>
<thead>
<tr>
<th>Zone</th>
<th>City Decrement constant</th>
<th>Time (s)</th>
<th>Suburban Decrement constant</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windschield</td>
<td>-1.7</td>
<td>2.21</td>
<td>-1.0</td>
<td>3.75</td>
</tr>
<tr>
<td>Left rear mirror</td>
<td>-1.5</td>
<td>2.50</td>
<td>-1.0</td>
<td>3.75</td>
</tr>
<tr>
<td>Right rear mirror</td>
<td>-2.0</td>
<td>1.88</td>
<td>-2.0</td>
<td>1.88</td>
</tr>
<tr>
<td>Inner rear mirror</td>
<td>-1.7</td>
<td>2.21</td>
<td>-1.5</td>
<td>2.50</td>
</tr>
<tr>
<td>MIU(^7)</td>
<td>-1.3</td>
<td>2.88</td>
<td>-1.0</td>
<td>3.75</td>
</tr>
<tr>
<td>Background</td>
<td>-1.7</td>
<td>2.21</td>
<td>-1.0</td>
<td>3.75</td>
</tr>
<tr>
<td>Face obstructed</td>
<td>-1.0</td>
<td>3.75</td>
<td>-1.0</td>
<td>3.75</td>
</tr>
<tr>
<td>Primary zone</td>
<td>No limit</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Distraction criterion of Holmström & Johansson, 2003**

The “Background zone” is the zone not covered by the other zones. “Face obstructed” refers to that the eye-tracking sometimes was obstructed. With these settings the ten drivers were categorized as distracted 9 times during a total time of 10x20 min=3h 20 min. The settings which constitute a driver distraction criterion were not theoretically supported other than that they built on the common sense assumption that the more a driver looks away from the middle of the road, measured both in time and angle of eccentricity, the worse it gets.

**Hypotheses**

**Blue Flash**

Attractive stimuli that might capture a person’s attention have been studied in experiments (Remington, Johnston, & Yantis, 1992; Yantis & Hillstrom, 1994).

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\(^6\) Following the definitions that were presented on p. 5.

\(^7\) Main Instrument Unit (speedometer etc.)
From these experiments it is concluded that abrupt visual onsets attract people’s attention, even involuntarily. This makes way for the idea to use abrupt visual onsets to attract a distracted driver’s gaze to the road. Such a stimulus would be different from an ordinary warning in the sense that it would be attractive in itself and therefore not require any type of interpretation by the driver. An abrupt onset that directs the attention of the driver to the road if the driver has been distracted by something should be located at a middle of the road position. This builds on the assumption that chances of finding information needed to accurately bound the field of safe travel and the minimum stopping zone are highest there (following our driver distraction definition on p. 7). Even if the driver looks away rather much, that is if gaze eccentricity from the middle-of-the road-position is high, it may be possible that the driver would be attentioned to it. There is much empirical evidence that peripheral vision is good, perhaps even better than foveal vision, for detecting new perceptual events in the visual field (Dember, 1960). To use a flashing light mounted on the dashboard so that it is reflected in the window approximately at middle of the road position could be one possible countermeasure. Since there are sources (e.g. Graham, 1965) claiming that, in the periphery, cone sensitivity to short wavelengths is relatively higher than it is in the fovea, the flash should be blue. A blue flash fulfils requirements 6 (not occlude), 7 (not auditive), and 10 (realizable) of our requirement list (p. 13). It requires empirical investigation to test the other requirements, however.

Brake Pulse
Since there has been previous research showing the efficiency of brake pulses in the context of collision warning systems, this may also be effective as a driver distraction countermeasure. A brake pulse fulfils requirements 6 (not occlude), 7 (not auditive), and 10 (realizable). Because of its discreetness there are reasons to believe that it also will fulfil requirement 8 (accepted). It requires empirical investigation to test the other requirements, however.

Our hypotheses are thus:

H1: A flashing blue light at middle of the road position is an effective driver distraction countermeasure.

H2: A brake pulse is an effective driver distraction countermeasure.

Methodological issues
Before we go on to the method chapter of this thesis, the different components of the methodology used will be discussed. This is done to provide a background for the methodological choices of the study. All the way, the goal was to make such choices so that the different aspects put forth in the requirement list on p. 13 should be covered and the hypotheses thus be addressed. The exception is the ninth requirement (reliable) that requires a temporally more extended study than is possible here.

Using an experiment
To evaluate the efficacy of the proposed distraction countermeasures and test our hypotheses, the best thing would be to assign people, by random sampling, to two groups. One group gets the driver distraction countermeasure system installed in
their cars and the other (control) group does not get any installation. After a year, or so, the accident statistics of these two groups could be compared and if there is a significant difference that is large enough, according to some predetermined criterion, to the advantage of the treatment group, then it could be recommended to the public to use that countermeasure.

Unfortunately, there are practical problems with this strategy, which means that the needed investment for a large-scale field study would not be defendable. First, the two groups must be very large for there to be any measurable difference between them, considering the relative small number of incidents that do occur. Second, we are far from knowing what an effective countermeasure system would look like. Third, since there is so little knowledge about driver distraction countermeasure effects, the safety risks are not known either, and to put drivers at risk would not be in line with fundamental ethical research principles. The research process has not come that far, and a large field study lies quite long ahead down the road. It is not until more knowledge exists about distraction countermeasures that such a study would be advisable. At present, much has to be discovered. Therefore, instead of using a field experiment that would have larger external validity, with direct measures such as accident rate, an experiment with indirect measures will be used.

The idea is to use an experimental setting in which subjects drive in a driving simulator. While driving in the simulator they are distracted by an in-vehicle distractor that makes the subjects shift their gaze to a head down position inside the car. When an eye gaze monitor records eye gaze into the car that exceeds a distraction criterion, a distraction countermeasure that should has the effect to redirect the subjects' gaze to the road is activated. By comparing glance times from the eye gaze monitor and reactions to a critical situation that occurs during look down, between conditions where countermeasures are used to a control where none are used. Glance time and critical situation reaction are indirect safety measures from which inferences about the efficiency of the countermeasures may be drawn.

Using a simulator

One of the problems with a large-scale field study is that it is impossible to guarantee the safety of the participants when the effects of the countermeasures are not known. By conducting experiments in a simulator no such risks exist. Further, conditions can be controlled to a larger degree in a simulated environment compared to real life. A simulator experiment will therefore be the method by which data is acquired in this study. The problem that simulator experiments face has to do with external validity, but at this stage in the research process this problem is considered to be smaller than the economic and safety problems of a field study.

Using eye-tracking equipment

A big advantage in this project is that a newly developed eye-tracking system, by SmartEye, was put to disposal. This is a system that uses two cameras that are mounted on the dashboard in the car, IR-lights, and digital image processing, to yield gaze directions of the driver. It is designed to provide information about where people look. The system looks for facial features and tries to figure out head position and eye gaze on basis of where these features are located. Car
manufacturers are interested in this technical solution since it is unobtrusive, i.e. no eye gaze helmet (see e.g. Harbluk, Noy, & Eizenman, 2000) or anything else that the driver has to wear is used. This means that it would work to have such a system, with cameras, installed as extra equipment in series produced cars. The cameras would then be used for monitoring the driver for attention support purposes, but could also be used for other purposes such as detecting the driver’s attitude and adapt air-bag blow-up, or automatically customize seat adjustment. This eye-tracking equipment is thus not only an interesting research tool, but also a commercially viable solution for the car industry.

There has been one previous study (Holmström & Johansson, 2003) that used the SmartEye system for tracking drivers’ eye gaze. The objective of that study was initially to determine parameters of a driver attention model by using the SmartEye eye-tracking system, but it was concluded that the SmartEye system was in a developing stage and was not reliable enough to be used as a research tool. Instead, the study focused on evaluation of the SmartEye system. With the recommendations of that study some of the problems have been solved, but there has not been a thorough validation study in a driving setting, as yet, of the SmartEye system. Together with the SmartEye eye-tracking software, a program has been developed that can be used for dividing the visual environment of the driver into different zones. This program was intended to be used to classify the attentional state of a driver and is called Inattention Decision Program, or IDP for short. It can be used to define zones such as the primary zone (activated when looking straight ahead), the center rear mirror zone (activated when looking into the center rear mirror), the main instrument unit zone (looking at the speedometer), etc.

Using a surrogate distractor: the S-IVIS (experiment distractor I)

A very important aspect of evaluating distraction countermeasures in an experimental setting is to get experimental control over the distraction itself. Since statistics suggest that in-vehicle distractors constitute the largest portion of the distraction problem (see Figure 1, p. 3) we will only focus on those in the experiment. There are a lot of potential distractors that a driver might be subjected to in a modern car. Crying children, learning how to operate a new radio, operating the navigation system, operating the audio system, picking up an object from the floor, dialing a phone number on the cellular phone, reading a paper map, etc are all examples of potential distractors. However, different distractors have different effect on different people. Something that is very distracting to one person could be immaterial to another. The problem is further complicated by the fact that the same distractor might affect the same persons differently on different occasions. For instance, a newly installed radio may be much more distracting to operate than a radio that is well known and understood by the driver. That is, all of the aforementioned distractors have a great intrapersonal and temporal variance as to their distractiveness. This poses a problem in an experimental setting since there is a need for a distractor that repeatedly and reliably distracts different people. Moreover, the distractor has to be calling for continuous attention since what we want to do is to see if our countermeasures have effect after a longer period of glance away from the road. That is, its tasks must not be chunkable so that the subject can choose to divide the task solving in visual chunks.
Different suggestions that could be used as a distractor were considered, e.g. visually demanding computer games. The final solution was to use a slightly modified version of the surrogate in-vehicle information system (S-IVIS) task developed by Natasha Merat at the Institute for Transport Studies at the University of Leeds, UK\(^8\) (Merat, 2003a). The task is designed to simulate the visual, motor, and cognitive demands on the driver that are comparable to real IVIS (e.g. a navigation system). It also fulfils the requirements of being stable between subjects (Merat, 2003b) and demands continuous visual attention.

The subject is prompted by a sound to look at a screen inside the car for every task presentation. The task is then to press a yes button when there is an arrow that points upwards in a matrix of arrows, otherwise the no button should be pressed.

![Figure 3: Examples of responses to S-IVIS](image)

Right answer: 'YES'

Right answer: 'NO'

The original S-IVIS was complemented with an auditive feedback signal which indicated right (pling) or wrong (beep) answers. This introduced a certain extent of game mechanism into the experiment situation and subjects seemed more motivated to correctly solve the task when auditive feedback was given. To use such a motivational cue is theoretically motivated by the Norman & Shallice model, described on p. 10 above, since it is not only sensory stimuli and the Supervisory Attentional System that make the subject attend the S-IVIS screen then, but also motivation. According to the theory, anything that motivates a person to engage in a schema (here the S-IVIS task solving schema) will increase its activation value. In this case the heightened activation value of the S-IVIS schema results in that the S-IVIS task becomes more distracting\(^9\).

The difficulty level of the S-IVIS task is altered in two ways. First, by using three different sizes of the matrix: 4x4, 5x5 and 6x6. Second, by having the non-target arrows turned in different directions or not. By having the non-target arrows turned in different directions makes the task more difficult. This is consistent with research that has shown that similarity between distractors (in this case the non-upward pointing arrows) facilitates search (Duncan & Humphreys, 1989). It is generally more difficult to find the upward pointing arrow in the right matrix than in the left matrix below. This means that the right-hand matrix requires longer average continuous glance times.

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\(^8\) The S-IVIS task has actually been developed in connection with the European HASTE project.

\(^9\) Cognitive psychologists Poulsen and Segalowitz have also explored motivation as a source for heightened schema activation. They conducted experiments to see how motivation affects attention (Poulsen & Segalowitz, 2000). By using a point system and auditory feedback these authors found that motivation manipulations selectively affected attention switching mechanisms, although basic response times were unaffected.
Figure 4: Examples of difficulty levels of S-IVIS tasks

Here, as with the simulator, the problems with choosing an experimental surrogate concern external validity, but the reliability of the distractor is considered more important in this experimental setting.

Using an ecological distractor: the glove box paper fall-out (experiment distractor II)
As already mentioned there is an abundant amount of possible distractors that a driver in a modern car might be subjected to. Therefore, as a complement to the S-IVIS task, another distractor was proposed early in the planning of the experiment. To distract the driver in a wholly different manner the sudden fall-out of paper from the glove box was used. This distraction event is very different from the S-IVIS distractor. In the way it was conceived, the glove box would suddenly burst without the subject’s knowledge about it, thus come as a surprise. The subjects themselves are free to react however they want as opposed to the S-IVIS task where there are right and wrong answers.

That this distractor had weaknesses compared to the S-IVIS was concluded before experimenting started. First, it is not possible to present it several times as a distractor, since the subject would soon learn that there is “not much to it”. Second, it does not require continuous attention. It is possible to chunk gaze time on the distractor, or for that matter not look on it at all. It is, however, interesting to compare the results of this kind of distractor to the results of the S-IVIS distractor.

Using an experimental distraction criterion
In this study which only aims at finding out how effective two proposed distraction countermeasures are, the distraction criterion could be rather conservative, that is not allowing the subject to look away from the road much. This in order to provide more experimental data. It does not have to be realistic in the sense that the criterion that is used in the experiment is a criterion that should be used in real life. The criterion should not be too conservative either because then there is a risk that the countermeasures are activated too frequently, leading to frustration of the subjects. Therefore, we choose a shorter time than 3.75 s that was used in the Holmström and Johansson (2003) study, but a longer time than the average glance times away from the road that were reported by the reviews of normal glance behavior cited on p. 10 (Green, 1999; Wierwille, 1993).

In the experimental setting, of the present study, there are predefined distractors (Experiment distractor I and II) which are located at the same position throughout the experiment. No other gaze directions than gaze on the road/main instrument
unit and gaze on the in-vehicle distractors are expected. It is therefore possible to make the simplification to have only two zones; Zone 1, which corresponds to gaze on the road, and Zone 2, which corresponds to gaze inside the car.

In the terms of the distraction criterion model discussed on p. 14 the initial budget is 3 s and the decrement constant 1. The increment constant will be set to infinity, which is a simplification, but no theoretical or other information was available to set this parameter more precisely.

Using steering reaction and glance duration times as dependent measures

The countermeasures should be evaluated along the lines of how they redirect the gaze of the driver to the road, according to requirements 1 (direct gaze to the road) and 3 (fast) of the requirement list (p. 13). A dependent measure that could work as an evaluation tool in this respect is in-vehicle glance duration time. By comparing in-vehicle glance duration time when countermeasures are active to a control group it could be possible to evaluate the countermeasures in terms of how they decrease in-vehicle glance duration time. The countermeasures are activated according to the chosen distraction criterion of 3 seconds. This glance duration measure with a distraction criterion closely operationalizes the definition of distraction that we have and is made possible by the SmartEye eye-tracking tool.

To meet requirement 2 (enhance ability to cope with critical situation) of the requirement list, the subject should be exposed to a critical situation while distracted and warned. Since the simulator that is used in this study has been validated for lane position (Harms, 1996; Törnros, 1998; Törnros, Harms, & Alm, 1997), but not for collision avoidance maneuvers, a steering reaction time measure is proposed. The car is turned towards the ditch while the subject is distracted by an in-vehicle distractor (the S-IVIS). This forces the subject to steer back on the road again with a swift maneuver to maintain lane position. See procedure of the method chapter, p. 26, for details.

Using other elicitation techniques

The dependent measures described so far may cover the three first items on the requirement list. To cover requirements 4 (unambiguous), 5 (not distract), and 8 (accepted), a questionnaire was designed that the subjects completed after the trial.

To acquire a possibility for a more qualitative analysis of reactions to the proposed countermeasures, video recordings were also made during the trials.
Method

The experiment was carried out in the VTI simulator and a within group counterbalanced design was used with three conditions; CONTROL, FLASH, and BRAKE. As dependent measures a steering reaction and a glance duration time were used. Other elicitation techniques for evaluation of the distraction countermeasures included a questionnaire and DVD recordings.

Equipment

The VTI simulator

The VTI driving simulator used in this study is made up of a visual system, a motion system and a sound system to simulate driving. The visual system is powered by computer graphics and presents an image of the virtual road with three projectors onto a 120 (width) x 30 (height) degrees screen. The motion system simulates acceleration motion with three degrees of freedom. Sideways ±3.5 m, pitch angle +15 degrees/-10 degrees, and roll angle ±24 degrees. The motion system is also complemented with a vibration table which the cabin is mounted upon which primarily is used for simulating the vibrations caused by the road-vehicle contact, but also for the simulation of small sudden movements. The vibration table has four degrees of freedom ±0.05 m vertically, 0.075 m longitudinally, a pitch angle of ±4 degrees and a roll angle of ±7 degrees. Forces of the motion system on the cabin are downscaled to a half of the forces they simulate. The sound system simulates road, wind and engine noise. The cabin itself was in this experiment a five-gear Volvo 850 that had been cut off just behind the front seat with the front seats, dashboard, steering wheel, and everything else in front of the B-column intact. The simulator logs data (e.g. steering wheel angle, speed, gear, etc.) at a maximum rate of 200 Hz.

The simulator can be used to simulate different kinds of driving environments like city traffic, rural road traffic, etc. It is possible to simulate real roads in the simulator; this has been done in validation studies of the VTI simulator (Harms, 1996; Törnros, 1998; Törnros et al., 1997). These studies have primarily focused on comparing the choice of speeds and lateral position for real driving and simulated driving. As of yet, there have been no validation studies of more complex behavior types such as how people react in critical situations.

The S-IVIS task distractor

For the S-IVIS task a touch screen mounted just below the air intake panel was used. In the modified version of the S-IVIS task used in this experiment, the text buttons were translated into Swedish. The brightness was set to a low level partly because the subjects then had to “look harder” for the up-pointing arrows and partly because it was easier for the experimenter to see what kind of picture that came on the screen via the sensitive monitoring camera that monitored how the subjects pushed on the S-IVIS screen. For a thorough description of the S-IVIS task see p. 18.
METHOD

Figure 5: Experiment setup

The glove box distractor
Another distractor used in the experiment was the sudden outburst of the glove department. The glove box door was locked by an electromagnet and inside was an empty coke can wrapped up in a paper magazine. When the current to the electromagnet was turned off, the paper magazine worked like a spring to open the glove box door resulting in that the coke can together with the magazine fell down on the passenger seat beside the driver. This event was a one-shot-only for each subject and the subjects were not told about it before the trial.

The Smart Eye system and IDP
The Smart Eye Pro Automotive 2.1 eye-tracking system was used in the experiment. Two cameras mounted on the dashboard and a customized personal computer was part of the hardware. For this particular system version, facial features had to be manually applied (by a lot of mouse clicking) to pictures of the subjects. These facial features were: left and right inner eyebrow, left and right outer and inner eye-corner, left and right nostril, left and right mouth corner, left and right ear and finally left and right eye center.

For this experiment seven snapshots were used to create the feature mask for eye-tracking: one facing straight ahead, two with the nose facing each camera, two with the nose straight ahead but with gaze into each camera, one shot with the subject looking at the S-IVIS screen just by slightly turning the head to look down, and another shot with the subject looking at the S-IVIS by both turning the head and leaning forward, i.e. with the face closer to the screen. There were thus 14x7x2 (features x snapshots x cameras) possible features to place in the proper positions for each subject. However, all features were not visible on all pictures, thereby mitigating the task for the experimenter who had to make the “feature mask”.

Together with the SmartEye system another software program, IDP, was used to define two visual zones, a head-up zone (Zone 1) and a head-down zone (Zone 2). The border between these two zones was where the dashboard met the windshield, with an indent of Zone 1 in the dashboard where the speedometer was so that looking at the speedometer activated Zone 1. Looking at the S-IVIS screen
activated Zone 2. The borders of these two zones had to be defined individually for each subject. In the figure below a subject is looking at the S-IVIS screen. The upper window is the SmartEye window. The lower window is the IDP window with the two zones.

![Image of SmartEye screen with IDP](image)

**Figure 6: SmartEye screen with IDP**

The Flash countermeasure

Twelve blue diodes powered by a potentiometer were mounted at the dashboard so that the blue light was reflected in the windshield approximately at middle of the road position. The blink cycle was 0.3 s with 0.1 s lights on and 0.2 lights off. All diodes blinked synchronously. Total blink time was maximum 1.4 s and blinking was interrupted if Zone 1 was reactivated (i.e. if subjects looked up).

The Brake countermeasure

The brake countermeasure was a single pulse that was simulated by a deceleration in the visual system of 2.5 m/s² during 2 s. The deceleration of the motion system was, however, smaller since the vibration table, the part of the motion system that can move at the speed which is required, had a limited pitch capacity. The deceleration force exerted on the cabin by the vibration table was 0.07 g.
METHOD

Subjects
The subjects were recruited through the VTI subject pool which is comprised of volunteers that have seen ads in the local newspaper and at the local job center or heard via other people that VTI needs subjects. In this way 16 female and 14 male subjects with an age from 18 to 52 years (mean 35.2, std 7.0) that did not wear glasses or make-up during the experiment were recruited. Glasses and make-up were banned since the pilot study had indicated that eye-tracking was worse with glasses and make-up. Driving experience varied among the subjects, from those who had just received their license up to those who had held their license for more than 30 years (mean 16.1 std 7.0). The subjects in the main study were numbered from 19 to 48 (lower subject numbers were used in the pilot study and as a buffer).

Procedure
The subjects were given written instructions that informed them about that the study was about how drivers can manage other tasks while driving a car and that different situations put different demands on the driver. Certain situations like driving in environments with a lot of other road users do not leave much room for other than the driving itself but at other times one should be able to carry out other things while driving, e.g. while driving in simpler environments such as on a freeway. Further, the subjects were instructed that only freeway driving would take place in this experiment. On the other side of the written instructions page, instructions for the S-IVIS task were given (see appendix A).

After the written instructions had been read by the subjects, the same instructions were repeated verbally by the experimenter making sure that the subjects had understood the S-IVIS task. Then the simulator was shown for the subjects and further instructions on how to record a movie and taking some still pictures for the personal profile that the eye-tracking system needed were given to the subjects. The movie and the pictures were taken directly and the experimenter who created the SmartEye personal profile (“feature mask”) could do so while the subject practiced on the S-IVIS task (14 presentations) and practiced driving the simulator for ten minutes. After the practice drive and when the profile and zones had been defined, the subjects were asked if they would like to have some coffee. This was offered since the pilots had shown that subjects easily got tired during the experiment. After these preparations the experiment began.

The road scenario was made as monotone as possible to make the driver willing to engage in the distraction task. The simulated road was a 110 km/h (~70 mph) freeway with no other traffic. One session lasted for an hour, 3600 seconds. During this time 84 S-IVIS presentations in 12 blocks were made. Each presentation lasted for maximum five seconds. If the subject had not pressed a button by then it was recorded as a “no answer” and the wrong answer beep sounded. The same thing happened if the subject looked away from Zone 2 before pressing a button. During the entire trial the subjects were monitored with the SmartEye eye-tracking system.

In each block there were seven S-IVIS presentations of which one was extra difficult (6x6 matrix and arrows in all directions). If the subjects looked down for more than 2 seconds during such a difficult presentation the car was automatically turned, gradually during 1.5 s, 1.5 degrees in the direction of the right hand ditch. This forced the subject to turn the wheel in order to avoid ending
up in the ditch. The yaw only took place if the subject looked down on the screen, or, to be exact, if Zone 2 was activated. If Zone 1 was activated, i.e. if the subject looked up again before 2 seconds, the yaw never set in. Moreover, if the subject looked up during the turn of the vehicle, the vehicle stopped turning, i.e. the yaw was interrupted. The time from yaw onset till the driver started to turn the wheel with a sudden steering wheel movement was measured and called steering reaction time. A sudden steering wheel movement was operationalized as steering wheel angle change to the left of more than two degrees that had to be continuous with an angle change rate of more than 0.020 degrees for each time frame (0.005 s). This criterion was set by analyzing the data from the pilot experiments.

All the S-IVIS presentation glance times from the start of the S-IVIS presentation to that the subject looked up, in other words, from Zone 2 activation to Zone 1 reactivation were measured. The glance time at difficult presentations was called glance duration time at difficult S-IVIS presentations.

During the experiment all of the subjects were subjected to three conditions – FLASH, BRAKE and CONTROL – each of which lasted for twenty minutes. The order of the conditions were counterbalanced between the 30 subjects and since there are 6 possible orders each condition order was replicated 5 times. The distraction criterion in the experiment was three seconds which means that the subjects were categorized as distracted if Zone 2 had been activated for more than three seconds. This means that during the twenty minutes that the FLASH condition lasted the diodes in the windshield started to flash after that Zone 2 had been activated for more than 3 seconds. When the subjects drove in the BRAKE condition the brake pulse was activated after 3 seconds of Zone 2 activation. In the CONTROL condition nothing happened when the driver met the distraction criterion.

Below is a schematic diagram of the hypothesized chain of events in the experimental setup at difficult S-IVIS presentations and how the different reaction times are related to these events and to each other. A third concept has also been added to the diagram and that is “visual processing time”, the time it takes after looking up before course heading is adjusted.

Figure 7: Hypothetical relation between variables
At the end of the trial, at 3505 s, the glove box burst and glance behavior for that distraction was registered. After the trial, the subjects filled out a questionnaire, filled out the pay check form (each subject received SEK 800 ~ 100$ or 90€) and were debriefed.

During the entire trial the subject was monitored visually via the SmartEye cameras, a subject monitoring camera, and a camera showing the S-IVIS screen and how the subject pressed the S-IVIS screen buttons. The simulated road scene that the subject saw was also presented to the experimenters on three separate LCD computer screens. The experiments could also hear via a microphone what was going on in the simulator cabin and could also talk to the subject via intercom. The subject monitoring camera picture, the S-IVIS camera picture, and the center road scene picture were recorded on a three field DVD.

Pilot experiment
Before the actual experiment took place a pilot experiment was conducted to test the procedure and the equipment and to see if the S-IVIS distraction task was distracting enough. As a result of the pilot experiment the feedback sound was added to the S-IVIS task and the yaw angle lowered from 2 to 1.5 degrees and the rule that when the subject looks up the yaw is interrupted. The criterion of a sudden steering wheel was also set by data from the pilot experiments. It was also noted that, by the reactions of the pilot experiment subjects, that the countermeasures could have effect.
Results

The distraction criterion was met 123 times during the CONTROL condition, 162 times during the FLASH condition, and 134 times during the BRAKE condition for all subjects during the entire experiment. Corresponding means are hence (n=30), 4.1, 5.4, and 4.5. At difficult S-IVIS presentations the criterion was met 41, 44, and 37 times respectively (means: 1.37, 1.47, and 1.23). Five subjects had more than half (229) of the total distraction events (419). The five subjects who had least distraction events only shared 1 distraction event. Only seventeen subjects were distracted in every condition. During the whole experiment drive that lasted 3600 s the mean eye-tracking fall-out for all subjects was 88.1 s (std=95.2) or 2.45%, ranging from 0.09% to 10.2% for the individual subjects (see appendix C-1). The first two subjects’ results for the beginning of the trial (28 first S-IVIS presentations) were disregarded in all of the calculations of the data since the eye-tracking equipment was extra unstable at that time.

Glance duration time after condition

The mean glance duration time at difficult S-IVIS presentations, on occasions when the distraction criterion was met (i.e. gaze down more than 3 seconds), was for the CONTROL condition 3.87 s (std=0.56), for the FLASH condition 3.86 s (std=0.44), and for the BRAKE condition 3.76 s (std=0.52). The mean glance duration times from look down to look up for all S-IVIS presentations on occasions when the distraction criterion was met was for the CONTROL condition 3.65 s (std=0.59), for the FLASH condition 3.68 s (0.62) and for the BRAKE condition 3.59 s (std=0.52). The high number of missing data, with only seventeen subjects being distracted in every condition, and the large variances compared to the mean differences between the conditions, prohibits and makes it unnecessary to carry out inferential statistical tests.

Figure 8: Glance duration results
Steering reaction time

Of the 122 distraction events at difficult S-IVIS presentations, the steering reaction criterion was met 103 times; 36 times in the CONTROL condition, 36 times in the FLASH condition, and 31 times in the BRAKE condition. The mean steering reaction time on these occasions was measured from yaw onset to that the subject started a sudden steering movement. This reaction time was 1.05 s (std=0.38) for the CONTROL condition. For the FLASH condition it was 1.10 s (std=0.51), and for the BRAKE condition it was 1.08 s (0.42). Here, as well as before, the high number of missing data and the large variances compared to the mean differences rule out an inferential statistical test.

![Steering reaction time at difficult S-IVIS](image)

**Figure 9: Steering reaction results**

Average visual processing time (steering reaction time – (glance duration time – 2 s)) is thus for the CONTROL condition ~0.82 s, for the FLASH condition ~0.76 s, and for the BRAKE condition ~0.68 s.

An example of steering data and glance data for an individual distraction event is presented in appendix C-3.

Glance duration times overall

The mean glance duration time of all 2,413 glance times on the S-IVIS for all subjects (n=30) was calculated to 2.11 s and the median to 1.97 s. Below is the distribution of glance durations shown.
RESULTS

Figure 10: Glance duration result histogram

18 % of the total number of 2,413 glances were longer than 3.00 s. Less than 5 % of the total number of glances on the S-IVIS were longer than 3.82 s (95th percentile). The 97.5th percentile was 4.30 s and the 99th percentile was 4.84 s. The average glance times for the difficult S-IVIS was 2.61 s. The means for every S-IVIS presentation is presented in appendix D-2. The standard deviations for the glance durations for each of the 84 presentations were calculated and the mean of these standard deviations was found to be 0.84 s. The mean of the standard deviations for the difficult S-IVIS was 1.03 s.

Average glance times after gender and age

The average of the average glance times for all females (n=16) was 1.76 s, the corresponding figure for males (n=14) was 2.56 s, the measured gender difference was thus 0.80 s or 45.3% of the lower value. Homogeneity of variance was tested and it was found that there was no significant difference in variance between the two groups F(13,15)=1.81, ns. A two-tailed t-test, assuming homogeneity of variance, revealed a significant difference between the means t(28)=4.91, p<0.01. The confidence interval around this observed difference is $CI_{99}=0.80\pm0.45$, i.e. with 99% confidence we can say that the difference between females’ and males’ glance times lies between 0.35 and 1.25 s.

The subjects were grouped into three age groups: 18-30, 31-40, and 41+. The average of the average glance times for subjects between 18-30 (n=6) was 2.06 s, the average for the 31-40 year-olds (n=18) was 2.22 s, and for the 41+ group (n=6) the average was 1.94 s. An ANOVA test showed that there were no significant differences between these three groups $F(2, 27) = 0.53$, ns.

S-IVIS answers

To see how well subjects answered the S-IVIS task, the 84 S-IVIS presentation answers were summarized. The average number of correct answers for all subjects
RESULTS

was 60.8 (std=10.3), the average number of wrong answers 6.4 (std=4.0) and the average number of “no answer” 16.8 (std=10.7). The mean for females/males was 58.3/63.7 (correct answer), 5.8/7.1 (wrong answer), and 19.9/13.1 (no answer). A statistical test was carried out to see if there was a significant difference between the sexes in number of correct answers. Homogeneity of variance was tested and it was found that there was no significant difference in variance between the two groups $F(13,15)=1.99, \text{ns}$. A one-tailed t-test, alpha = 0.01, assuming homogeneity of variance, testing the null-hypothesis that the females did not have less correct answers showed that there was no significant difference between the means $t(28)=1.45, \text{ns}$.

Glove box distractor glance behavior

A general characteristic for glove box distractor glance behavior was that glance time off the road was chunked, i.e. the subjects looked back and forth between the road and the passenger seat. The in-vehicle glances that were not separated by more than 10 seconds of on the road glances were categorized as being a part of the reaction to the glove box distractor. Mean in-car single glance length was 0.62 s (std=0.37) for those glances. Mean number of glances was 2.27 (std=1.39). For all subjects’ glove box distractor glance behavior see appendix D.

Questionnaire

The subjects responded to the questions in the questionnaire by checking one of seven boxes. The leftmost box was labeled “not at all” and the rightmost box “very”. In the data analysis, the “not at all”-category corresponds to 1 and “very” to 7.

The results of some selected questions about what the subject thought of the countermeasures were:

<table>
<thead>
<tr>
<th>Item</th>
<th>Question</th>
<th>CM</th>
<th>Median</th>
<th>Mean</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>12d</td>
<td>Draws attention upon itself</td>
<td>FLASH</td>
<td>6</td>
<td>5.0</td>
<td>1.9</td>
</tr>
<tr>
<td>12e</td>
<td>Draws attention upon the road</td>
<td>FLASH</td>
<td>4</td>
<td>4.1</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>What did you think of the strong brake pulse?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10d</td>
<td>Draws attention upon itself</td>
<td>BRAKE</td>
<td>5</td>
<td>4.6</td>
<td>1.5</td>
</tr>
<tr>
<td>10e</td>
<td>Draws attention upon the road</td>
<td>BRAKE</td>
<td>5</td>
<td>4.8</td>
<td>1.5</td>
</tr>
<tr>
<td>13</td>
<td>Do you think that the flashing blue light would be a good part of an anti-distraction system in cars?</td>
<td>FLASH</td>
<td>4</td>
<td>4.4</td>
<td>1.8</td>
</tr>
<tr>
<td>11</td>
<td>Do you think that the strong brake pulse would be a good part of an anti-distraction system in cars?</td>
<td>BRAKE</td>
<td>5</td>
<td>4.5</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Table 2: Questionnaire results
RESULTS

To see if there was a difference between how subjects answered question 12d and 12e a Mann-Whitney U test for large samples (Hinkle, Wiersma, & Jurs, 1998) was carried out which showed that there was no significant difference between the subjects’ answers $U=310$, $z=0.21$, $ns$.

One question asked about how much money the subjects would be willing to spend on an anti-distraction system. The answers varied from the equivalent of 0€ to 2,250€; the median was 100€. The medians, means and standard deviations of all the questionnaire items are presented in appendix B.

Video recordings

The video recordings were used to analyze the effect of the kinesthetic brake pulse for every time (134 times) it was activated. The mean glance duration time for every category was also calculated.

<table>
<thead>
<tr>
<th>Category</th>
<th>Observed behavior</th>
<th>Number of events</th>
<th>Mean glance duration time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No reaction to brake pulse</td>
<td>9</td>
<td>4.55</td>
</tr>
<tr>
<td>2</td>
<td>The subject pushes S-IVIS button, then the brake pulse comes but difficult to say if it is the brake pulse that makes the subject look up</td>
<td>32</td>
<td>3.49</td>
</tr>
<tr>
<td>3</td>
<td>The subject looks up briefly because of the brake pulse, but down again to try to solve S-IVIS task</td>
<td>25</td>
<td>3.95</td>
</tr>
<tr>
<td>4</td>
<td>The subject seems alerted by brake pulse</td>
<td>3</td>
<td>3.92</td>
</tr>
<tr>
<td>5</td>
<td>The brake pulse has clear effect</td>
<td>7</td>
<td>3.85</td>
</tr>
<tr>
<td>NO</td>
<td>The brake pulse is not visible on video</td>
<td>11</td>
<td>3.45</td>
</tr>
<tr>
<td>LATE</td>
<td>The subject has looked up before the brake pulse comes</td>
<td>47</td>
<td>3.24</td>
</tr>
</tbody>
</table>

Table 3: Video results

Category 5 “The brake pulse has clear effect”, means that the subject feels the brake pulse and as a reaction looks up on the road. Category 3 is similar to 5, but with the difference that the subject does not keep gaze on the road as a reaction to the brake pulse, but looks down again.
Discussion

The aim of this study was to evaluate two proposed countermeasures and explore methodological techniques for doing so. A requirement list was made (p. 13) that was to guide the evaluation of the countermeasures. We said that the flash and brake countermeasures a priori fulfilled requirements 6 (not occlude), 7 (not auditive), and 10 (realizable) of this list. We then said that it requires empirical investigation to test the other requirements. An experiment was thus designed to see whether the countermeasures directed gaze to the road (1), enhanced ability to cope with a critical situation (2), whether they were fast (3), unambiguous (4), undistracting (5), and accepted (8). That the countermeasures were reliable (9) after long periods of usage and despite large variations in the ambient environment was not made the objective of the study.

A glance duration measure was used to address the first and third issues. A steering reaction measure was used to address the second issue. A combination of questionnaire questions and the quantitative measures was used to acquire knowledge about the countermeasures in respect to requirements 4, 5, and 8.

The results show that neither of the proposed countermeasures contributed to lower the glance duration away from the road or lower the steering reaction time. According to the experiment, requirements 1, 2, and 3 were therefore not fulfilled. There was a very slight tendency that the BRAKE condition produced lower times than the FLASH and the CONTROL group in both quantitative measures, but this tendency is statistically insignificant. The subjects' answers to the two questions about how much the flash drew the attention upon itself and how much attention it drew upon the road was 6/7 and 4/7 respectively. This difference was not significant, but the tendency might suggest that the flash countermeasure did not fulfill requirements 4 (unambiguous) and 5 (undistracting). For the brake countermeasure there was no such difference (5/7 for both questions) which means that the questionnaire could not show that the brake countermeasure was ambiguous or distracting. The subjects had a slight tendency to think better of the brake pulse than of the flash also when they were asked whether the countermeasure would be a good part of an anti-distraction system in cars (Flash=4/7 and Brake=5/7). This suggests that compared with the flash, the brake pulse was a slightly better alternative. However, the difference is very slight and far from significant. The subjects ratings in this issue were not convincing which means that the question whether requirement 8 (accepted) has been met remains open.

The groups that had a significant difference in glance times were not the groups of the different conditions. The only difference that was found was the difference between females and males in overall off-road glance time. This is interesting because it suggest that one of the sources for higher male crash involvement, as described elsewhere (Al-Balbissi, 2003), may have to do with attention behavior.

That no significant differences for steering reaction time and glance duration time were found between the treatment groups and the control group may either depend on an actual lack of efficiency of the countermeasures or on methodological shortcomings. Both these alternatives will now be discussed.
Inefficient countermeasures

The countermeasures that were chosen were chosen because previous research had indicated that there is a possibility that they would be effective. A brake pulse had been used by Shutko (1999) and Dingus (1996). Their experiments were, however, on-the-road studies and so they could use a strong brake pulse (0.3 g and 0.2 g respectively). The motion base of the simulator that was used in this study only provided a limited brake force that was much lower (0.07 g) than the one used in previous research. Although the pilot experiment had indicated that the brake pulse might have effect, it was maybe too weak for showing an effect in the dependent measures used in the study. If intensified, it might perhaps show more effect. The video analysis category “NO” (11 occasions) also suggests that the brake pulse was too soft. In the video analysis, on occasions when the brake pulse was categorized as having clear effect, the average glance time was not much lower (3.85 s) than the CONTROL group average glance time (3.87 s). This may also indicate that the glance duration measure used in this study is not appropriate for evaluating brake pulses. We will soon discuss the glance duration measure more below.

The previous research that was an argument for using a flash as a countermeasure was the results of experiments that had shown that sudden visual onsets capture attention (Remington et al., 1992; Yantis & Hillstrom, 1994). These results were, however, based on laboratory experiments and only slight differences in response times due to interference of stimuli in non-target positions was the basis for the authors to claim that sudden visual onsets capture attention. The character of the conditions in the present study was quite different, and transfer of the Remington et al. effect to the conditions of the driver distraction context was perhaps only limited. That there was a tendency that the subjects thought the flash drew more attention to itself than to the road also suggests that the flash as it was designed in this experiment is not optimal as a countermeasure.

The discussion whether or not to allow auditory signals should also come up again, since any effect of the brake pulse and the flash could not be shown. Since many other studies have fruitfully used auditory signals as warning signals, and a large part of drivers do have hearing intact, the seventh requirement, not auditive, of the countermeasure requirement list should perhaps be excluded.

Methodological shortcomings

The most important elicitation techniques that were used in the experiment were eye-tracking and simulator logging, which rendered the two measures of glance duration and steering reaction. Neither of these two measures has been satisfyingly validated before the experiment. We will now discuss, in light of the results of the experiment, what the flaws of these measures were and what is needed to develop them. The derivative of glance duration time and steering reaction time – visual processing time – will also be discussed. Then five other possible error sources will be discussed.

Glance duration time

Many studies have studied driver glance behavior (Green, 1999; Harbluk et al., 2000; Land & Lee, 1994; Wierwille, 1993). The automatic and unobtrusive kind of
DISCUSSION

eye-tracking that was used in this study has, however, not been so widely used yet. This technology has, nevertheless, a good potential for becoming a good research tool and driver attention support system component in future cars. Enhancements must, however, be made to and thorough validation be carried out of the SmartEye system before it is further used as a research tool, to ensure exact measurement.

The average eye-tracking fallout rate of 2.45% is far too high, especially when one considers the fact that it is at the most crucial moments, when the driver changes gaze and head direction, that fallout is as biggest. It is suspected that the SmartEye system has a lag, i.e. that it does not follow gaze as closely as would be desired. The automaticity of the system must also be increased to increase reliability. First, the feature mask must be automatically generated. Second, the zones must be the same for all drivers, i.e. when two different drivers look at the same point in the driving environment the resulting measurement output should be the same. This second point has to do with that the coordinate system should not be person based, but vehicle based. To increase precision of the glance duration measure, the fixations should be possible to measure so that in-vehicle glance duration time is measured from the last fixation on the road before look down to the first fixation on the road after look up. In this study the time started and stopped somewhere in between fixations on the road and on the distractors.

A more rigorous evaluation of the SmartEye system than that carried out by Holmström & Johansson (2003) is needed. Comparisons of the SmartEye system may be made to a competing system on the market produced by SeeingMachines. This system has undergone a partial validation (Victor, Blomberg, & Zelinsky, 2001) of the kind that is urged for with the SmartEye system. To validate the exact measurement of the SmartEye system would need a set of experiments and possible enhancement iterations of its own.

We mentioned above that the glance duration measure might not at all be ideal to evaluate distraction countermeasures. When the video analysis showed that the break pulse had clear effect the average glance duration was not much smaller than for the CONTROL group. This may be due to the aforementioned lack of precision in the eye-tracking equipment, but could also be due to something else.

Steering reaction time

The steering reaction criterion was met on 84% (103/122 occasions) of the difficult S-IVIS presentations when the subjects reached the distraction criterion. Here, fallout depends largely on that the subjects made steering wheel movements before the turn set in or had a high steering wheel angle variability, making the yaw seem small. It could even be so that the artificial yaw resulted in that the car was turned into lane, in cases when the car was heading to the left just before the yaw. The definition of a sudden steering wheel movement may also be revised. Fallout was largely due to the character of the yaw, but it may also be the case that the criterion resulted in that too many steering reactions were reported. In one calculation the criterion was changed so that only steering wheel movements that were more than 3 degrees were recorded. This did, however, not lead to fewer false alarms but rather to more misses. In the steering reaction criterion

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10 It still had to be continuous with an angle change rate of more than 0.020 degrees for each time frame (0.005 s).
that was chosen for this experiment it was the continuity of the movement and the total size of the movement which were most emphasized. The swiftness of motion was less weighted since a steering wheel speed of 4 degrees/second sufficed to fulfill the requirement.

The validity of the steering reaction measure may also be questioned since the required turning of the car towards the ditch when the driver looks inside the car is a rather artificial intervention. However, it may have revealed interesting aspects of vision of distracted drivers that have to do with peripheral vision. This is what will be discussed next.

**Visual processing time**

It was anticipated that the subjects would look up before they started their sudden steering wheel movement away from the ditch. The result was, however, that most subjects started to steer away from the ditch before they looked up. The following figure is a modification of Figure 7 following these results.

![Figure 11: Result relation between variables](image)

There could, at least, be three reasons to why the visual processing time was negative in the experiment. It could be due to lag of the eye-tracking system, it could be due to that the steering reaction measure criterion was too sensitive, or, more interestingly, it could be explained by that steering is sufficiently subserved by peripheral vision. The two first sources of this deviation from the hypothesis have already been discussed. Let us see what the third means.

Is it possible that the participants in the study are able to react to the artificial yaw while looking at the in-vehicle distractor? There are indeed studies that suggest that detection and spatial orientation may only require peripheral and not foveal vision to work. A study by Lamble, Laakso, & Summala (1999) “showed modest losses in drivers' detection abilities, in terms of TTC, in closing headway situations when the driver’s visual attention was focused away from the road scene ahead.” (p. 814). Their subjects could react to a decelerating car ahead by braking while focusing gaze on in-vehicle tasks inside the car.

If steering is regarded as a spatial orientation task the following passage from Leibowitz (1986) is interesting: “because spatial orientation can be adequately
subservied by low spatial frequencies, visual guidance is quite adequate in the peripheral fields (Leibowitz, Post, Brandt, & Dichigians, 1982). This can be illustrated by our ability to walk or drive a vehicle when vision is blurred or with a mask covering the central field.” (p. 605). This could mean that we may look at an in-vehicle location and still keep lane and may therefore explain how a negative “visual processing time” is possible. The deception of artificially yawing the car may also still work since “spatial orientation is carried out reflexively with minimal awareness” (ibid. p. 605), which could explain why the subjects are not aware of what made them turn the wheel.

Missing data
There were altogether 2520 (84x30) S-IVIS presentations, but only 2413 (96%) glances into zone 2 during these presentations. 56 of the missing glances are explained by subjects 19&20:s fallout in the control condition. The remaining 51 non-look down cases, which are probably mostly due to eye-tracking problems, are distributed among 11 subjects. Of the 360 (12x30) possible glance duration data points at difficult S-IVIS are only 122 (34%) over 3 s. Mean glance time was 2.61 s. This is probably mostly due to that the distraction criterion was high and that the difference in difficulty between difficult and non-difficult S-IVIS presentations was not large enough. Of the 122 possible steering reaction data points, when the subjects were categorized as distracted at difficult S-IVIS, only 103 (84%) were recorded. This is probably mostly due to that the steering reaction criterion had its flaws (see above) and that the yaw was not large enough.

All the missing data described above, together with the small glance time mean differences between the conditions, resulted in that an ANOVA test was not carried out. There were only seventeen subjects who were distracted in all conditions and in order to be able to use a dependent samples ANOVA, data from all subjects must be available.

Nuisance warnings
The effect of the countermeasures could have been lessened by the many false alarms. There were in total 296 activations of the countermeasures. 81 of these occurred when the vehicle was turned towards the ditch, i.e. when the driver was subjected to an actual close call. On the other 215 occasions, the countermeasures were activated without anything dangerous or close callish occurring in the environment. Since nothing dangerous occurred in the environment at those 215 occasions, the countermeasure activations could be interpreted as false alarms or nuisance warnings. Repeated nuisance warnings may lead to that warnings eventually will be ignored. This could have been the case in our experiment.

Insufficient distractors
If the two glance duration histograms that have been presented previously (on pp. 9 and 30), are compared it is clear that the S-IVIS results in longer glances off the road than was the case in the Hada study (1994). The median glance time off the road for all S-IVIS of 1.97 s is, however, comparable to the study by Kimura et al. (1990) that had medians up to 2.0 s. The average glance time for the difficult S-IVIS of 2.61 s is considerably higher than what is reported by any of the glance time sources that were presented in the introduction. The S-IVIS distractor was chosen because it was said that it might have the ability to continually distract
most subjects for a relatively long time. The relatively high glance duration means
and low standard deviations suggest that the S-IVIS is a fairly good distractor in
that respect. However, it was not enough in combination with other experimental
flaws to distract the subjects reliably.

If the simplification that gaze is equal to attention does not hold, then the S-IVIS
might perhaps not be a distractor at all. This reasoning is supported by the
negative visual processing time discussed above. If the drivers were not really
distracted in the sense that they did not take their mind off the road, could
explain why there was a lack of significant results in the steering reaction
measure.

The results of the glove box distractor were much different from the S-IVIS
results. They are more similar to glance behavior that is described in Wierwille
(1993). The variance between subjects, how many glances and how long these
glances are makes it clear that the glove box distractor is not useful when
extended continuous glance times are wanted.

Non-precise hypotheses
It is not only the countermeasures per se or the used methodology that have flaws.
We may conclude from the discussion up to now that the hypothesis formulation
was flawed. If the hypothesis formulation had been more precise (for instance
detailing the force of the brake pulse), perhaps some of the problems of the study
would not have occurred. However, at this stage of the research process, things
have to be discovered and hopefully the hypotheses of future studies on this
subject will be more acute.

Lack of separation between the effect of the countermeasures and
the psychological force to look on the road
The psychological force to look on the road was described above (p. 9) and it was
concluded that it is very rare that subjects look away from the road for longer
intervals of time. What this study wanted to investigate was, however, behavior of
subjects who do look away from the road for longer intervals of time and to see
what could be done to redirect their gaze to the road again. It was therefore
necessary to expose the subjects to a task, which resulted in extreme glance times
off the road. Then the next step was to measure the effect of a countermeasure
that redirects the gaze to the road again. However, when gaze has been off the
road for such a long time it could be the psychological force to look on the road and
not the countermeasure that makes the subject look back. To separate the effect of
the countermeasures from the psychological force to look on the road is therefore
difficult. This may be the most important explanation to why there were no
differences between the treatment groups and control group in this experiment.

With more reliable eye-tracking, a lower difficulty level of the non-difficult S-IVIS
tasks, which would lead to less false alarms, and a lower distraction criterion it
would perhaps be possible to see an effect of the brake pulse countermeasure. But
that result would still be contaminated by the psychological force to look on the
road.
A comprehensive attention support system

We have now discussed the possible inefficiency of the countermeasures and the possible shortcomings of the methodology of this study. It remains, however, to discuss the distraction countermeasure idea. To solve driver distraction problems with a distraction countermeasure system, and a driver distraction criterion, as they have been defined in this thesis (p. 11 and 14), is perhaps not a viable solution. To have a driver distraction criterion expressed in seconds without using any other information about the driver-vehicle-road system is questionable. Far too many false alarms or a uselessly liberal distraction criterion would be the result of such a system. It would perhaps be better if sensor information about the driver's gaze is used as a complement to other sensor information about the driver-vehicle-road system. Examples of which parameters other sensors could gather information about is: drowsiness, head-way, time to collision, lane position, speed, road type, etc.

A comprehensive attention support system could perhaps be made up of the following parts: a) sensor-technology; b) criteria for what sufficient attention is which must be adaptive to vehicle capability, driver capability, driving environment, and effector capability; and c) effector-technology.

Research questions that are made topical include: Which information about the driver-vehicle-road system do we need to algorithmically assess whether the system is in a state of hazardous distraction?; How can driver status, environment status, and vehicle status be measured?; Which measure/s are most reliable/feasible?; What should be the distraction criterion? (with this question the signal detection problem is brought to the fore, i.e. the trade off between false alarms, and misses, of a supposed attention criterion); and finally, Which realerting effectors are effective?

All of these questions must be seriously addressed before an attention support system is properly realized. In this master thesis the focus has been on the latter of the questions, i.e. the evaluation of possible effector-technologies, although fully developed sensing technologies and algorithms were not available in the project. It would perhaps have been better if the fact that step a and b were not fulfilled had been recognized at an earlier stage in this project. As it were now, unfinished, non-validated technology and algorithms, were used for steps a and b. The results would perhaps had been better if the effector technology research of this thesis either had had proper sensor technology and criterias, or had been completely decoupled from the driving situation.
Conclusion

Although no effects of the proposed driving distraction countermeasures could be shown, has this thesis:

- Integrated the driving theory of Gibson & Crooks into a driver distraction definition.
- Presented a requirement list for realerting stimuli (that also could apply to a comprehensive attention support system).
- Collected data in a simulator environment of responses to and glance behavior connected to a surrogate in-vehicle information system.
- Showed that there is a difference in in-vehicle glance time between females and males in the experiment set-up used, which is consistent with the greater crash involvement of males.
- Suggested that people do not always first look on the road before they initiate steering maneuvers.

In the future it is recommended that research should focus on comprehensive attention support systems, integrating information from different sensors and not only rely on eye-tracking information. Before eye-tracking equipment is used it should be thoroughly validated and have a very low fall-out rate. If kinesthetic brake pulses are to be used as realerting stimuli, the force that they exert should not be too weak.

This is what can be concluded with this thesis, and hopefully it has contributed with knowledge as to mitigate the effects of driver distraction so that the number of accidents on the world’s roads can be reduced.
References


REFERENCES


Appendices

A – Translated written instructions

In the study you will participate, we want to know to which extent drivers can manage other tasks while driving a car. Certain situations may put a high demand on the driver like in urban areas where there are a lot of other road users to consider and where pedestrians and cyclists often move in unpredictable ways. That type of situations does of course not leave much room for other than the driving itself. On the other hand at other times one should be able to carry out quite a lot of other things while driving, e.g. while driving in simpler environments such as on a freeway. In this study, you will only be driving on freeway.

In the middle of the car under the air intake panel is a screen where arrows will show up. If there is any upward pointing arrow on the screen, press "YES". Otherwise press "NO". Do not answer before you are sure, because you cannot change your answer. Two examples with squares of arrows are shown below.

Right answer: ‘NO’

Right answer: ‘YES’
B – Translated questionnaire with results

Questions after simulator drive

To be filled out by the experimenter
Date: Subject:


   Median: 1200
   Mean: 2051.7
   Std: 2092.3 Max: 10,000 Min: 500

[Comment: A Swedish mile is 10 km]

2. a) If you drive something apart from cars, which kind of vehicle do you then drive?

   Only five answers

   __________________________

   b) How big part of your total mileage do you drive this kind of vehicle?

   _____________ Swedish miles

   Median: 16.5
   Mean: 16.1
   Std: 7.0

3. For how long time have you held a driver’s license? _____________ years

4. How motion sick did you get driving the simulator?

   Not at all ☐ ☐ ☐ ☐ ☐ ☐ ☐ Very

   Median: 1
   Mean: 1.6
   Std: 1.1
5. How distracted were you by the arrows task?

Not at all □ □ □□ □ □ □ Very

Median: 3.5
Mean: 3.5
Std: 1.5

6. What distracts you normally during driving?

Frequency of answers mentioning:
Children: 6
Stereo/Radio/CD: 8
Cellular phone: 10
Traffic: 8
(7 subjects did not write anything)

7. How much did you think that the arrows task resembled things that make you distracted during normal driving?

Not at all □ □ □ □□ □ □ □ Very

Median: 4
Mean: 3.7
Std: 1.4

8. How distracted were you when the glove department burst?

Not at all □ □□ □ □ □ □ □ Very

Median: 2.5
Mean: 3.2
Std: 1.9
9. How much did you think that the glove department over-flow resembles things that make you distracted during normal driving?

Not at all □ □ □ □ □ □ □ Very

Median: 4
Mean: 3.8
Std: 1.7

10. What did you think of the strong brake pulse?

a.  Freighting

Not at all □ □ □ □ □ □ □ Very

Median: 2
Mean: 2.6
Std: 1.3

b.  Dangerous

Not at all □ □ □ □ □ □ □ Very

Median: 2
Mean: 2.2
Std: 1.4

c.  Makes you alert/wakes you up

Not at all □ □ □ □ □ □ □ Very

Median: 5
Mean: 4.8
Std: 1.3

d.  Draws attention upon itself

Not at all □ □ □ □ □ □ □ Very

Median: 5
Mean: 4.6
Std: 1.5
Appendices

e. Draws attention upon the road

Not at all □ □ □ □ ☐ □ □ Very

Median: 5
Mean: 4.8
Std: 1.5

f. Easy to understand

Not at all □ □ □ ☐ □ □ □ Very

Median: 4
Mean: 3.9
Std: 1.6

g. Warning

Not at all □ □ □ ☐ ☐ □ □ Very

Median: 5
Mean: 4.5
Std: 1.7

11. Do you think that the brake pulse would be a good part of an anti-distraction system in cars?

Not at all □ □ □ ☐ ☐ □ □ Very

Median: 5
Mean: 4.5
Std: 1.6
12. What did you think of the blue flashing light?

a. Freighting

Not at all □ ☒ □ □ □ □ □ □ Very

Median: 2
Mean: 2.3
Std: 1.4

b. Dangerous

Not at all □ ☒ □ □ □ □ □ □ Very

Median: 2
Mean: 2.0
Std: 1.2

c. Makes you alert/wakes you up

Not at all □ □ □ □ ☒ □ □ □ Very

Median: 5
Mean: 5.0
Std: 1.7

d. Draws attention upon itself

Not at all □ □ □ □ ☒ □ □ Very

Median: 6
Mean: 5.0
Std: 1.9

e. Draws attention upon the road

Not at all □ □ ☒ □ □ □ □ Very

Median: 4
Mean: 4.1
Std: 1.8
f. Easy to understand
Not at all □ □ □ □ □ □ Very

Median: 4
Mean: 4.2
Std: 1.9

g. Warning
Not at all □ □ □ □ □ □ Very

Median: 4
Mean: 4.6
Std: 1.7

13. Do you think that the flashing blue light would be a good part of an anti-distraction system in cars?

Not at all □ □ □ □ □ □ Very

Median: 4
Mean: 4.4
Std: 1.8

14. How much would you be willing to spend on a system that warns you when you are distracted?

Median: 1000
Mean: 2631
Std: 4312 Max: 22,500 Min: 0

SEK _________________
15. How did you feel about having two cameras pointed at your face?

a. Unpleasant
Not at all □ □ □ □ □ □ Very

Median: 1
Mean: 1.5
Std: 1

b. You felt surveilled
Not at all □ □ □ □ □ □ Very

Median: 1
Mean: 2
Std: 1.4

c. One pulls oneself together because of them
Not at all □ □ □ □ □ □ Very

Median: 2
Mean: 2.7
Std: 1.8

16. If you summarize your impression of driving the simulator, how big did you think the resemblance with driving a car was?

Not at all □ □ □ □ □ □ Very

Median: 5.5
Mean: 5.1
Std: 1.4

17. How realistic did you think the road, the surroundings, and the objects on the road were?

Not at all □ □ □ □ □ □ Very

Median: 5
Mean: 4.5
Std: 1.4
We have recorded your drive on video. The primary purpose is to have the possibility to go back and watch the video if we come across anomalies in the data. But it could also be of interest for us in the future to have the possibility to use the video at research conferences in the future. We do not pass around the video to people outside VTI.

Do you consent that the video is used for these purposes?

☐ Yes
☐ No

Date Signature

Linköping _____________ ____________________________
C – Diagrams

C-1

Eye-tracking fallouts

C-2

Average glance duration for each S-IVIS presentation
C-3 Combined glance time and steering angle graph

In this graph the x-axis has two functions, steering wheel angle for the full line, and glance duration time for the shaded line. The y-axis represents time. At y=2 is a dotted line representing the start of an S-IVIS presentation. At x=2 is a dotted line representing yaw-onset, and at x=3 is a dotted line representing the distraction criterion. When the shaded line crosses the yaw onset line (i.e. when the subject has looked down for two seconds), the yaw starts, and when the distraction criterion line is crossed a countermeasure sets in unless the subject is in the CONTROL condition as is the case in this particular example. Here subject #25 is subjected to its first difficult S-IVIS presentation.

![Steering wheel angle and S-IVIS glance time](image-url)
D – Glance duration times for glove box

The glance lengths of glances on the glove box burst are given below in seconds. “Between” refers to the time between glances.

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58
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Evaluating driver distraction countermeasures

Statistics showing that in-vehicle driver distraction is a major contributing cause in road accidents is presented. Driver distraction is defined building on the driving theory by Gibson and Crooks. The idea to use driver distraction countermeasures as a way of mitigating the effects of the driver distraction problem is then introduced. A requirement list is formulated with ten requirements that distraction countermeasures should meet. A simplification of regarding distraction as a gaze direction problem makes way for designing an experiment to evaluate two driver distraction countermeasures in which new eye- tracking technology plays a key role. The experiment also makes use of a simulator, a surrogate in-vehicle information system as a distractor, and thirty subjects. The most important dependent measures were in-vehicle glance time and a steering wheel reaction time measure. The evaluated countermeasures – a blue flash at middle of the road position and a kinesthetic brake pulse – could, however, not be shown to meet the most important of the requirements formulated. The lack of effect of the countermeasures in the experiment may either depend on their actual inefficiency or on methodological shortcomings of the experiment. These alternatives are discussed. It is speculated that the biggest problems with the possible lack of actual efficiency have to do with that the theoretical basis for using a flash did not transfer to the driving setting, and that the brake pulse used was too weak. The methodological problems have to do with the non-validated dependent measures used, missing data, nuisance warnings, insufficient distractors, non-precise hypotheses, and difficulties with separating the effect of the countermeasures from the psychological force to look on the road.

Keywords
Driving Behavior, Accident Prevention, Attention, Distraction, Simulators, Eye Movements