Interacting with In-Vehicle Systems: Understanding, Measuring, and Evaluating Attention

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ABSTRACT
In-vehicle systems research is becoming a significant field as the market for in-vehicle systems continue to grow. As a consequence, researchers are increasingly concerned with opportunities and limitations of HCI in a moving vehicle. Especially aspects of attention constitute a challenge for in-vehicle systems development. This paper seeks to remedy this by defining and exemplifying attention understandings. 100 papers were classified in a two-fold perspective; under what settings are in-vehicle systems evaluated and how is driver attention measured in regard to in-vehicle systems HCI. A breakdown of the distribution of driving settings and measures is presented and the impact of driver attention is discussed. The classification revealed that most of the studies were conducted in driving simulators and real traffic driving, while lateral and longitudinal control and eye behaviour were the most used measures.

Author Keywords
In-vehicle systems, IVS, attention, literature classification, test track, driving simulator, measures, and driving settings.

INTRODUCTION

The in-vehicle systems (IVS) market has grown by a factor ten during the last generation [6]. In-vehicle systems now include embedded mini computers, navigation systems and televisions to name a few. Car manufacturers do not expect this development to stagnate and as Broy [6] states, the next generation will bear witness to an exponential growth of the in-vehicle systems domain.

The environment for in-vehicle system interaction is highly dynamic and interactive, and criteria regarding usability, learning ability, efficiency, memorization, error handling and satisfaction, have been extended also to comprise the requirement that driver distraction must be avoided. Wheatley [31] describes the driving context as a physically variable environment in terms of noise, light levels and space availability that is unpredictable by nature. Hence, the primary task is subjected to a high visual load with variable cognitive load, leaving only whatever resources remain for secondary task interaction.

Avoiding distraction and attention deficits in the driving task is the predominant challenge in in-vehicle systems development and as such an in-vehicle system should aim at taking the fewest resources from the driver. Attention to the primary task has always been an important issue in car manufacturing and car engineers have for the most part been able to come up with solutions that do not demand (visual) attention; throttle control, brakes, gear shift lever, clutch, etc. Traditional sources of internal distraction such as conversations with passengers, eating, drinking, lighting a cigarette, etc. [27] have now been supplemented with interaction with more or less elaborate information systems. This makes driver attention and appropriate secondary task interaction design as topical as ever.

While these systems are all useful in one or more important ways, they also conspire to an increasing load on the driver's attention resources since eyes and mind also are engaged away from the road and hands are employed elsewhere than on the wheel. This raises the concern that in-vehicle systems tend to become a safety risk to the driver, not to mention potential passengers and other drivers, as it is widely accepted that drivers engaging in visually and/or manually complex tasks tend to be more involved in accidents [16]. Because of the thought-provoking relationship between car accidents and in-vehicle system usage, the rapid development of in-vehicle systems is associated with an increasing scepticism (see e.g. [4, 22, 24, 25]). Attention is a concept that cannot be neglected when dealing with in-vehicle systems and understanding attention will be a tremendous help when contemplating, designing and evaluating in-vehicle systems.

The objective of this paper is to deliver an understanding of attention by defining the concept and by presenting specific findings on attention from the literature. To this end, further insight into the literature on attention is needed. Green [10] stresses the need for research studies gathering information on the impact of in-vehicle system usage while driving, particularly the role of driver attention in order to organize models that engineers can apply. According to Katz et al. [14], the foundation for carrying out research studies about attention is to establish frameworks for measurements – what, why, and how. Thus, a second objective of this paper is to provide such a framework. The framework will be based on two important factors for understanding and evaluating attention in in-vehicle systems, namely a) to what extent do attention related studies include the driving element and b) which measures are used to determine the presence and impact of attention. The result of this classification of attention related studies according to these two categories will carry with it a much needed overview of the most commonly used settings and measures.

DRIVER ATTENTION AND DISTRACTION

Attention spans several dimensions suggesting different types of scenarios and measures for evaluation of in-vehicle systems in order to comply with the driving and avoiding in-vehicle interaction caused attention problems. The below listed concepts and definitions will serve as a conceptual framework when presenting the approaches taken in existing research to measure and discuss attention in relation to in-vehicle systems.

Basically, Eysenck defines attention as the human's ability to concentrate on certain objects and allocate processing resources accordingly [8]. It can be seen as a telescope with which we point at things around us to make them stand out, thus when we place our attention on something, we ignore others. Although we try to devote attention to several things at the same time (designated *divided attention*), our ability to do so is limited. Kahneman [13] explains that people do have some control over the allocation of mental capacity of attention, which principally is affected by two factors: (a) intention and experience, which refers to the policy of giving higher priority to objects, which we are more interested in or familiar with and (b) evaluation of demands, which refers to our ability to evaluate the demands on capacity when there are several things around us, and give attention to the ones who need immediate attention or the ones who require lower capacity to handle. In a mobile environment dynamic objects often obtain the human's attention over static objects or an object that is currently paid attention to [13].

Distraction can be defined as anything that somehow takes away attention from the primary task. In the case of driver distraction, this is anything that takes the driver's attention away from the driving task. As stated by Green [11], the use of the notion of distraction to categorize vehicle crashes embraces everything from bees in cars to noisy children in the back seat to billboards with racy images. However, to form a framework for evaluation and measurement of attention and distraction, a more applicable designation of the concepts is needed.

Driver distraction can manifest itself in several ways [28]. The *withdrawal of attention* from the driving scene is the most commonly mentioned. According to Brown's [5] classification, withdrawal of attention can be divided into two types; *general* and *selective*. A general withdrawal of attention refers to an insufficient perception, typically visual, of the driving information. This can be due to eye glances away from the road scene, also known as *eyes-off-the-road* distraction. Normally drivers depend heavily on the visual perception on the driving task. According to Seppelt and Wickens, 90% of the feedback the driver gets from driving is visual [21]. However, other sources of information from the physical environment, such as auditory or tactile feedback, need to be collected for safe driving. In-vehicle tasks will compete for the attention resources if the primary and secondary tasks draw on the same perceptual resource. Thus, two tasks that require the same kind of perceptual attention are more difficult to concurrently execute than two task that require attention of two different perception channels, e.g. visual and auditory [32]. As a consequense, Wickens and Hollands suggest that perceptual resources needed for secondary task interaction can be distributed over multiple senses, to mitigate decline in primary task performance [32].

A *selective* withdrawal of attention (corresponds *mind-off-the-road* distraction by Green [12]) seems to be an insidious type of distraction, because it deals with mental processing, e.g. perceptual interpretation, memory processes, decision selection, or decision execution, which requires attention and may reduce the total amount of attention capacity considerably [12]. This is the kind of attention deficits commonly associated with daydreaming, conversing with other passengers or talking on the phone, and can lead to a selective filtering of information based on expectations rather than the actual situation [28]. The concept is defined as *inattention blindness*, referring to the phenomenon where drivers fail to "see" an object in the driving environment, though they are looking directly at it [26]. Inattention is characterized as a shift of attention away from the driving task for non-compelling reasons, where distraction is a shift of attention for compelling reasons [19].

Another form of distraction described by Tijerina [28] is *biomechanical interference* or *mechanical interference* which refers to when the body shifts out of the neutral driving position, e.g., leaning to see something or taking the hand off the steering wheel to manipulate a device. The interference can degrade the driver's ability to execute driving manoeuvres and thereby constitutes safety risks.

A topic that is often mentioned in relation to attention and distraction is *workload*, which by Strayer et al. [20] is defined as the amount of processing resources used per time unit, for task performance. For this matter two concepts are pointed out; *overload* and *underload*. Overload occurs when a secondary task, typically a task not related to driving, makes exclusive use of one or several processing modalities, i.e. mental, perceptual or motor mechanical, which are requisites for the primary task of driving [17]. In-vehicle systems are one of the culprits regarding driver overload, because the interaction with the systems to a substantial extent draws on the same resources as the driving task. Whereas most of the literature regarding in-vehicle systems and workload is concentrated on the problem of overload, there is also a point being made about driver *underload* [7]. This is primarily the case for automated driving assistance systems, since they may result in drivers being over reliant and lower the driver's level of attention, effectively decreasing his/her chance of detecting dangers in time to do anything about them [18].

As presented, attention is not easily defined or restricted to a single concept. However, in our classification of literature we have opted not to distinguish between the individual papers' definitions of attention. Instead we aim to provide an overview of how attention evaluations are conducted and measured and in this regard the individual papers' interpretations of attention will not be included.

CLASSIFICATION FRAMEWORK

The papers reviewed in this paper have been selected from a larger research study on in-vehicle systems interaction. This study used a rather rigorous approach, which can be found described in detail in [1]. The study consisted of a review of 289 papers which were all read by two of the authors. A data sheet with information such as title, author, journal, publisher, year of publishing, number of pages, etc. was created for each of the papers, and in this process, each data sheet was augmented with an abstract and a set of topics. These topics have served as a basis for selecting appropriate papers for this classification of attention related literature. From the 289 papers, we retrieved the papers that had been flagged with topics that indicated relevance for the focus of this classification (e.g. attention overload, attention underload, distraction, focused attention, divided attention, or inattention blindness), which resulted in 181 papers. These 181 papers were then subjected to a series of eliminations. First we sorted out papers that did not present any study (including experiment and evaluation) with attention related issues. Second, we removed "duplicate experiment papers", to make sure an experiment only existed once in the papers. This narrowed down the list to the final 100 papers used in this classification. These are presented in the appendix of reviewed attention papers. We will distinguish appendix papers from references by denoting them by their index in italic font style, i.e. [*10*] refers to the paper with index 10 in the appendix list, and [10] refers to the paper with index 10 in the reference list.

Driving Settings

Based on our own previous studies [2, 3], we define four *driving settings* that are characterized by the degree to which they incorporate driving elements and is used as general term for the conditions being used for attention research. These driving settings have been selected and defined specifically for this paper and have been constructed based on initially reading. While the driving settings are discrete it should be noted that some of the driving settings could be divided into multiple driving settings and that the line between them can be considered fluid. However, the driving settings are based on their individual and distinct relation to the driving activity and in this regard we believe they are useful for the classification.

No Driving

The *no driving* setting are used in studies that do not involve a scenario that tries to resemble a driving activity (though some seek to approximate the attention level of driving, for instance by replicating isolated elements from driving). An experiment involving reaction times is a typical example, where participants could for instance be asked to push a button when an indicator lamp comes alight. As these elements only serve to mimic a secluded (and in itself artificial) part of the driving task, we have chosen to place such studies in the *no driving* category.

Simulated Driving

Simulated driving refers to studies conducted in a so-called driving simulator. Driving simulators can be of varying qualities and fidelity. Stanton [23] stated that the realism of a driving simulation should be measured by its degree of *physical* and *functional fidelity*. Physical fidelity refers to the degree to which the driving simulator *looks* like the real environment and functional fidelity, the degree to which the driving simulator *behaves* like the real environment. Hence, there exist low-fidelity, medium-fidelity and high-fidelity driving simulators in regard to the fulfilment of the two issues that apply to creating realism in a driving simulator. We will not distinguish between the various degrees to which a given simulation is realistic. Therefore, any experiment that uses a setup that can be considered a simulation of driving is placed in this category.

Controlled Driving

Controlled driving refers to real driving that takes place in a real car, but where the driving takes place in a controlled environment with variables that can be adjusted for the purpose of the driving session. This is typically driving that takes place on a closed circuit or test track where one is able to control the amount of traffic or be specific about the way the participant should drive the car. If the driving featured in a study is subjected to a controlled environment, it will be placed in this category, regardless of the degree of realism.

Real Traffic Driving

Real traffic driving is limited to studies that take their research into the actual and intended use context. Real traffic driving has characteristics that make the studies less controllable and furthermore this setting provides some safety-critical/ethical issues that may make it hard to conduct experiments, especially in regards to attention. Real traffic driving is characterized by autonomous agents such as other drivers or soft road users who are uncontrollable and unpredictable. When placing a paper in this category, we have opted not to consider properties such as traffic density or the difficulty of the road used for the experiment. While some studies feature real traffic driving that is somewhat controlled, for instance by placing a lead vehicle in front of the evaluation vehicle, we have still placed these studies in this driving setting.

The descriptions of the driving settings make it obvious that they differ in realism and control and that these parameters are difficult to reconcile. These driving settings will serve as one of our classification categories, to investigate the relationship between the driving settings and the research purposes. The other category we will classify the papers by concern the attention measures used in the studies.

Attention Measures

The above presented definitions of attention and distraction (and variations of these concepts) outline some of the properties of attention measures. As described, a general withdrawal of attention refers to an insufficient perception, typically visual and manifests itself in both degraded vehicle control and degraded object and event detection. This suggests a focus on indicators or metrics of driving performance and eye glance behaviour for measuring this kind of driver distraction. The selective withdrawal of attention is however more difficult to determine, since it manifests itself in degraded object and event detection, while vehicle control remains largely unaffected. This somewhat limits the ways to measure this kind of distraction directly; however some indirect measurements can be employed.

According to Green [12], the attention measures to investigate the safety-relevant distraction effect induced by secondary tasks can be divided into four categories; *primary task performance*, *secondary task performance*, *physiological measures* and *subjective assessments*. In addition a category for *eye glance behaviour* is included because of the importance visual perception has for driving a vehicle. The most important and frequently used measures under these categories are pointed out by Green [12]; Katz, et al. [14]; Tijerina [28]; and Tsimhoni, O., Yoo, H. and Green, P. [29], and are summarized below. We will use these categories to classify the papers according to what attention measures they use.

Primary Task Performance

Concerning aspects of vehicle control, this category is closely related to attention and distraction, since lack of vehicle control can degrade driving performance due to changes in the driver's mental and perceptual attention capacity. The primary measures in this category are: *lateral control* (e.g. lane excursions, steering wheel input), *longitudinal control* (e.g. speed maintenance, break pedal application, throttle angle deviation), c*ar following performance* (e.g. time-to-collision, distance to a leading car), and *driver reaction* (e.g. time spent on adopting to an unexpected incident).

Secondary Task Performance

The secondary task performance category includes all the performance measures related to secondary task interaction, i.e. all tasks which entail manipulation of an in-vehicle system while driving. The primary metrics in this category are *task effectiveness* (e.g. interaction errors, task completion) and *task efficiency* (e.g. task completion time using biomechanical interference measures, such as *hands-off-wheel time* or *eyes-off-the-road time*)

Eye Glance Behaviour

Driver eye glance behaviour is a very relevant measure to be taken into account because of the impact of (lack of) visual attention on the driving task. The primary metrics in this category are: *eye glance frequency, eye glance duration*, and *eye scanning patterns* (e.g. measurements of where the driver looks, for instance by means of eye tracking or electrooculography).

Physiological Measures

In the sense that the human body is a mirror of the internal conditions, physiological measures can serve as indicators for workload, including stress level and attention capacity. The primary measures are: *electrocardiogram* (e.g. heart rate and blood pressure variability), *body temperature*, *skin conductance*, *respiration* and *electromyogram* (e.g. muscle contraction).

Subjective Assessments

Subjective assessments of workload or stress can be useful to discover participants' perceptions of the workload and attention capacity before, during, and after an evaluation. There are a number of workload ratings; however SWAT and NASA-TLX are the commonly used techniques in the in-vehicle systems genre [14].

RESULTS

Results are summarized in table 1. Lateral control is the most commonly used attention measure, followed by longitudinal control with representation in 41% and 35% of the papers respectively. Car following performance and driver reaction times are used in 16% and 30% of the papers. Most of the primary task measures are obviously only used in driving settings that involve either simulated, controlled or real traffic driving; however measures of driver reaction times are also present in some of the studies conducted with no driving. In addition to this, Table 1 shows that driving reaction is the most used primary task measure used in studies with no driving or controlled driving, and is also one of the most commonly used measures across driving settings. This can be explained by the fact that a considerable amount of the studies that include driver reaction times as a measure are conducted in laboratories or on test track facilities focusing on driver reaction while performing various secondary tasks (e.g. [*27, 44, 54*]). Secondary task effectiveness is the most frequently used measurement with representation in 44% of the papers. This measurement typically refers to the number of errors in the particular task execution, like incorrect answers to logical or memory tasks (e.g. [*3, 13, 21*]) and interaction errors with the in-vehicle system evaluated (e.g. [*13, 26, 60*]), etc. Task efficiency is used in 21% of the papers and is often constituted by task completion times using a data log (e.g. [*50*]) or some of the other measures, such as *eyes-off-the-road-time* (e.g. [*6, 87, 90*]). Task effectiveness is well-distributed over the four driving settings; however it constitutes a relatively larger portion with no driving than in the other settings, which is due to a higher representation of research with a focus on secondary task performance, like the aforementioned examples, which do not necessarily imply driving tasks. However, task efficiency is in many papers related to the driving performance (e.g. [*12, 23, 39*]) and it is not as popular in no driving as the task effectiveness measure.

		No Driving (N=16)	Simulated Driving (N=52)	Controlled Driving (N=7)	Real Traffic Driving (N=30)
Primary Task	**Lateral Control (N=41)**	74	3, 4, 12, 15, 16, 34, 35, 39, 41, 42, 43, 45, 46, 47, 48, 49, 51, 52, 53, 57, 72, 73, 78, 84, 88, 89, 90, 92, 95, 97	1, 85	9, 11, 14, 23, 29, 50, 94, 100
	Longitudinal Control (N=35)	74	4, 15, 16, 20, 34, 35, 39, 42, 45, 49, 51, 52, 53, 78, 79, 84, 89, 91, 94	1, 27, 55, 85	9, 11, 23, 29, 50, 64, 66, 68, 71, 79, 94, 100
	Car Following Performance (N=16)		16, 20, 39, 51, 52, 73, 78, 79, 82, 83, 84, 89	44	40, 71, 79
	Driver Reaction (N=30)	8, 17, 32, 37, 54, 56	3, 5, 8, 22, 33, 36, 45, 47, 57, 75, 80, 83, 84, 88, 91, 92, 97	1, 27, 28, 44, 55	8, 23, 39, 60
Secondary Task	**Task Effectiveness (N=44)**	7, 13, 25, 38, 54, 56, 77	3, 4, 5, 6, 21, 22, 24, 33, 39, 41, 42, 43, 48, 53, 54, 72, 75, 81, 83, 88, 89, 97	27, 44, 85	6, 9, 11, 18, 23, 26, 40, 50, 59, 60, 63, 64, 65
	Task Efficiency (N=21)	8, 38, 74	6, 8, 12, 21, 39, 43, 53, 58, 89, 90	85	6, 8, 11, 14, 23, 50, 59, 67, 76, 87
Eye Glance Behaviour	**Eye Glance Frequency (N=28)**	38, 54	10, 12, 41, 46, 47, 53, 62, 69, 73, 79, 81, 89, 90	1, 85	9, 14, 23, 59, 63, 64, 65, 66, 68, 76, 79, 87
	Eye Glance Duration (N=27)	38, 54, 70, 96, 99	10, 12, 41, 46, 53, 62, 69, 73, 79, 81, 83, 89, 90, 95	1, 85	14, 23, 59, 64, 65, 79, 87
	Eye Scanning Patterns (N=16)	38, 54	24, 69, 73, 83, 97	85	14, 19, 29, 64, 65, 76, 79, 86
	Physiological Measurements (N=10)		15, 16, 69, 97		19, 30, 50, 59, 68, 94
	Subjective Assessments (N=30)	8, 98	3, 4, 8, 15, 16, 22, 42, 43, 47, 48, 51, 53, 58, 88, 89, 92, 93, 95, 97	1, 2, 44	8, 9, 14, 23, 29, 31, 59, 61, 63, 94

Table 1. Classification of attention measures distributed over driving settings. Numbers refer to indexes in the appendix of reviewed papers. N indicates the number of unique papers in the respective categories

Eye glance frequency and eye glance duration measures are used in 28% and 27% of the papers, whereas eye-scanning patterns are measured in 16% of the papers. In most papers both frequency and duration measurements are used complementary to each other (e.g. [*10, 38, 65*]). Eye scanning pattern data is in most papers collected with special made eye tracking equipment (e.g. [*76, 79, 86*]).

Physiological measures are used in 10% of the papers and thus, the least used measures. Electrocardiogram is the predominant of these measures and it is used in all studies using physiological measures, whereas other physiological measurements, such as body temperature (see [*69*]), skin conductance (see [*30, 68, 69, 94*]), respiration (see [*30, 69*]), and electromyogram (see [*30*]) are used only by a single or few papers. The physiological measures are used in connection with simulated driving and real traffic driving and serve to detect changes in driver attention capacity and driver workload (e.g. [*15, 50, 97*]).

Subjective assessments of workload and attention capacity are used in 30% of the papers, especially in connection with simulated driving and real traffic driving. An array of different assessment techniques and questionnaires is used in the papers; however the NASA-TLX assessment is the most commonly used (e.g. [*42, 62, 91*]).

DISCUSSION AND CONCLUSION

In this section, we will try to establish an understanding of the concept of driver attention by drawing out key elements from the classification and exemplifying these with qualitative findings from the classified papers.

Understanding Driver Attention

Green stresses the urgent need for research studies on the impact of in-vehicle system usage while driving [10]. This notion is in line with much of the research that aims to understand the field of in-vehicle systems and should be used in development of standards, guidelines, rules and methods that can serve in the engineering phase.

A common example of studies done for understanding is research studies of cell phones' impact on driver distraction and driving performance [*3, 27, 29, 56, 67, 75, 80, 86*]. It is well established that cell phone usage impairs the driving performance significantly. Research found that drivers engaging in cell phone conversation using either a hand-held or hands-free device, are more than twice as likely to miss traffic signals and often fail to see billboards and other signs, than when they are not distracted by the cell phone conversation [*81*]. This indicates that conversing on a cellular phone causes inattention blindness disrupting the driver's visual attention to the driving environment. In addition drivers react more slowly to changes in traffic patterns, when they are engaged in a cell phone conversation, which can be designated as change blindness [*60, 81*]. It is needless to say, that these driver states are insidious to driving safety and several studies and statistics lay evidence to this claim [*38, 63, 67, 80*]. A comprehensive study of accident reports found that 24% of the 669 individuals involved in accidents during the study period had used their cell phones during the 10 minutes preceding the accident [*67*].

Several studies on cell phone induced distraction deal with the relationship between the effects of biomechanical interference, such as dialling and holding the phone, and the mental processing of information while conversing (e.g. [*3, 56, 60, 80, 92*]). It is well stated, that the psychomotor aspects of cell phone use per se only constitute a minor factor in the deterioration of driving performance compared to the verbal task. In some studies passive verbal tasks, such as listening to the radio were not found to interfere with the driving task, while conversation with a hand-held or a hands-free cell phone, including listening to a partner and generating responses did disrupt driving performance [*39, 80*]. In regard to cell phones, the content of the conversation is far more important for driving and driver distraction than the type of telephone. The more difficult and complex the conversation is the greater the possible negative effect on driver distraction [*60, 92*].

Although the selective withdrawal of attention, or mind-off-the-road, seems to be the more insidious type of attention failures, the general withdrawal, or eyes-off-the-road, seems to be the more common. Because of the importance of sight in the driving task, information on the driver eye glance behaviour is gathered, such as numbers of glances and fixation times, in studies of a variety of driving tasks (e.g. [*38, 41, 46, 54*]). Some of the results include, that on average, a driver spends approximately 0.78 seconds (SD=0.65) and 1.26 glances (SD=0.40) to read a speedometer and 1.10 seconds (SD = 0.30) to check the left mirror [*46*]. Other studies, [*70, 99*] suggest that drivers are reluctant to go without roadway information for more than 2 seconds (dubbed the "2-second rule"). Analysis of driver eye glance behaviour indicates that total eyes-off-the-road durations of greater than 2 seconds significantly increase crash risk whereas eye glance durations less than 2 seconds do not significantly increase risk relative to normal, baseline driving [*38*]. Research results as these have led to a set of safety guidelines for designing in-vehicle systems with focus on visual attention, for instance that an average of 2.7 glances and a total of 4.10 seconds fixation time are the maximum values allowed when driving at 30km/h [*46*], or that glances to displays should not be longer than 2.5 seconds [*1*] or 1.5 seconds [*96*]. Even though the research results and guidelines differ, they clearly point to the fact that only a limited amount of information can be conveyed safely to the driver. As a result, any design of new in-vehicle system must not overload the driver perceptually. Thus, if in-vehicle systems interaction can be designed such that it has only few glances and low fixation times, or simply has no interaction induced visual demands; it may very well increase safety while driving.

There is a substantial number of studies examining possible interaction technologies for reducing the visual perceptual load. In the literature speech recognition and text-to-speech technology are pointed out as possible remedies to reduce visual demands (e.g. [*13, 23, 29, 86, 100*]). A common assumption pertaining to speech technology for in-vehicle systems is that speech-based interactions do not distract drivers, because drivers are not required to take their eyes off the road or their hands off the steering wheel. Studies [*13, 23, 29*] have shown benefits in such an "eyes-free, hands-free" method of interaction for in-vehicle systems in empirical terms. Nevertheless, voice-based interactions are not effortless and they have the potential to place cognitive demands on drivers with mind-off-the-road as a consequence [*86, 100*]. Although speech-based interaction offers promising alternatives to visual-based interfaces, the opinions are divided, since growing evidence suggest that systems with speech technology impose cognitive load on drivers that can affect driving performance.

Another approach pointed out as an eyes-free method of interaction is gestures as illustrated by Alpern and Minardo [*4*]. Where existing gesture-interface research has centred on controlling the user's primary task, this study explores the use of gestures to control secondary tasks while driving. In a wizard of Oz based driving simulator experiment, test participants performed entertainment tasks, (e.g. find a song, search presets, adjust volume) with both a gesture interface on the windshield and a standard radio installed in the simulator. Drivers in the gesture condition made fewer driving errors than with the physical interface but the difference was not significant. In qualitative interviews after the experiment, the participants preferred the gesture interface over the radio, because they could keep eyes and attention on the driving task and did not have to reach and touch anything, and could be less precise with the gestures. While these results are far from conclusive, they suggest gesture interfaces can be used as safely as a physical radio and seems to be a viable alternative for completing secondary tasks in the car. More research is needed to identify the potential and limitations of gestures as a secondary task interaction technology.

Evaluating Driver Attention

Many of the studies were conducted in simulated driving (51%) and this tendency could be explained by the rapid start-up phase that in-vehicle systems development is subjected to. Moreover this driving setting offers a number of benefits; it provides precise control over all elements to create identical and repeatable scenarios. Furthermore, simulated driving allows researchers to analyze risky scenarios without endangering a participant. Therefore, simulated driving is often used to design and evaluate scenarios that would not be feasible or ethical in real driving, whether it is in a controlled driving setting or in a real traffic driving setting. Hence, simulated driving is beneficial in areas where controlled driving and real traffic driving are limited; making simulated driving a popular option in safety research programs [*98*].

Controlled driving studies represent a step closer to real world driving. How big a step depends on the nature of the course and the research protocol. An interesting finding within this driving setting was the fact that only seven studies were conducted in controlled driving. This gives rise to the possibility that test tracks or other closed circuits are not considered to be worth the effort or simply do not bring enough added value along. Investigating the seven studies reveal that the geographical place is limited to only five different places; two of them related to universities. This seems to indicate that experiments in controlled driving is troublesome to arrange compared to the added value in reference to simulated driving or that the controllability does not make it up for the safety issues that real driving involves. The papers do not argue for the choice of controlled driving, and this raises the question, whether this driving setting really is worth the hassle? Whatever the case, this finding sets the stage for an examination of the three driving settings that involve some version of driving. However, a critical issue in this regard is the ability to create comparable scenarios in simulated driving and real driving.

The limitations in simulated driving and controlled driving do not imply that these methods cannot be used to gather useful information. As stated by Goodman et al. [7], each of them has a place in safety research, particularly as a means to minimize safety hazards in exploratory research. However, it is important not to be blind to the limitations of the methods and the need for validation by means of studies in real traffic. The latter driving setting provides the greatest degree of realism. Hence, research in real traffic driving has a high representation of observational studies (e.g. [*18, 26, 79*]) because real traffic driving provides the driver with real driving task demands.

Measuring Driver Attention

Safety and attention cannot be measured directly, although indirect measures are applied. Table 1 shows that primary task measures such as lateral control (e.g. measurement of lane keeping performance) and longitudinal control (e.g. speed maintenance) are commonly used measures of driver distraction related to secondary task interaction (e.g. [*3, 12, 34, 39, 44*]). Therefore, it is quite common to make inferences, such that higher driver workload when interacting with an in-vehicle system implies greater lateral movement and more frequent lane exceedences. It is interesting to note that a measure such as the number and length of lane exceedences during in-vehicle interaction is not considered primarily safety-relevant by everyone. Some argue that if there is no other traffic users nearby, if the lane exceedence is small or of short duration, or if the lane exceedence or speed reduction reflects the driver's strategy for compensation and reducing workload during concurrent task execution, there is no safety implication at all [*16, 50*].

This is an interesting line of reasoning, because it contradicts accident research and statistics that indicate that distraction related crashes are more likely during good conditions, i.e. in daytime, good weather, moderate traffic density, when the drivers think everything is fine [11]. Therefore, it seems injudicious to conduct comparative studies of different in-vehicle systems, find that one induces substantially more lane exceedences and still declare such results irrelevant unless there happened to be a crash hazard exposure.

Driver eye glance behaviour measures are often used, primarily because of the importance of vision in driving [*1, 24, 38, 41, 53*]. Eye glance behaviour is often measured by the glances a driver makes to a specific in-vehicle system while driving, i.e. the number of times the driver glances away from the scene view to look at the display and the length of these glances [*1*]. Eye fixation (when the eyes can be said to dwell on something), typically glances over 0.5 seconds, is often used as an indicator for to which objects the driver's attention is directed [*24*].

While measures of eye glance behaviour, in association with lateral control and longitudinal control, are used as detectors of general withdrawal of attention, it does not necessarily say anything about the selective withdrawal of attention that might be associated with in-vehicle systems. This is especially the case for in-vehicle systems that do not demand visual resources, such as speech-based interaction systems. During interaction with these systems, the driver's eyes can be kept on the road and hands on the steering wheel, serving the fundamental conditions for lane keeping and speed maintenance; however the mind might be elsewhere than on the driving task. Therefore other measures, such as reaction time and car following performance are used, as a way to measure the selective withdrawal of attention, by determining the driver's ability to react to external stimuli while interacting with the in-vehicle system. As table 1 illustrates, studies with reaction time are typically conducted in environments, where driving conditions, if any, such as road traffic, traffic lights, signs, and pedestrians are non-existent or controlled.

The results of the classification indicate that, whether how people drive, how to measure driver attention or whether it concerns causal relationships between in-vehicle systems and driving performance, much of the research contribute to an understanding of a fairly new research field. Katz, et al. [14] stress the importance of agreeing on a set of measures as the most important and predictive ones to be used as guidelines for engineers. Without agreement, engineers cannot verify claims that a specific design is safer to use or more suited for secondary task interaction. In this regard, different rules and guidelines have been developed to accommodate engineers. Although researchers roughly agree on a set of metrics to measure attention by, they do not necessarily agree on how the rules should be defined. For instance, it is interesting that widespread measures, such as lateral control and longitudinal control are not outlined in the literature. In addition, Green [*25*] introduced the 15 second-rule that states that the time allowed for completing a navigation system task involving manual controls and visual displays when the task is performed when not in motion, should be 15 seconds. However, Tijerina et al. [*85*] have disputed the applicability of this rule, since the plausibility of accurately determining whether a device adheres to the rule is limited. Furthermore, Salvucci states that the rule ignores many clearly important factors such as conflicting modalities between interaction and driving [*74*].

FURTHER WORK

Based on the above classification and discussion of the research into attention measures and driving settings for in-vehicle systems, a need for further research presents itself.

Though most of the studies realize the need for innovation or enhancement of the interaction techniques available for in-vehicle systems, there are very few attempts to redeem this situation. Furthermore, the results have stressed that research on which driving setting is the more appropriate for in-vehicle system studies is needed, which demands a direct pair-wise comparison of driving settings. In this regard it is especially interesting whether there is added value in using controlled driving over simulated driving, or if the problems associated with this kind of evaluation outweighs the extra realism.

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APPENDIX: REVIEWED ATTENTION PAPERS

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