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Assessing **D**istraction of **V**ehicle drivers in **E**urope from **R**oadside **T**echnology-based **S**ignage.

The safety effects of (digital) roadside advertising: an overview of the literature

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The safety effects of (digital) roadside advertising: an overview of the literature

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Glossary of Terms

Attention
Orientation to sensory events; detection of objects or event for cognitive processing, and the maintenance of a vigilant state.

Billboard
Surface that displays an advertisement.

Distraction
A diversion of attention away from activities critical for safe driving toward a competing activity.

Dwell time
Total amount of time the driver fixates at an object (e.g. a billboard) when the driver passes this object.

LED-screen
Surface composed out of Light Emitting Diodes (LED). These screens emit light and on these screens advertisements can be displayed. These advertisements can be displayed for a given period of time and then digitally be replaced by another (static digital billboards). These billboards can also display advertisements with moving images (video billboards).

Fixation
Period of time the visual gaze is on a single location.

Roadside advertising
All kinds of visible expressions road users can see that promote a product, event or activity.

Static digital billboard
One light emitting screen or a light emitting screen composed out of various screens that displays a static advertisement (i.e. an advertisement in which nothing moves). This static advertisement is digitally replaced by another static advertisement after it has been displayed for a given time.

SPI
Safety Performance Indicator: data-based parameter used for monitoring and assessing safety performance. Crashes are rare events and the stretches of road a billboard may cause a crash are small. Therefore, the impact of billboards on crash rates is not known most of the times.

However, it is possible to measure driver behaviour in the vicinity of billboards, for instance gaze behaviour. When drivers look for an extended period of time at an external object, the crash risk increases (Dingus et al., 2016). Because there is a relationship between crash risk and gaze behaviour, gaze behaviour is a SPI.

Traditional static billboard
Billboard that displays one advertisement continuously. An old advertisement has to be removed and new advertisement put up manually. Traditional static billboards can be illuminated.

Video billboard
A light emitting screen or a light emitting screen composed out of various screens that displays videos or moving animations.

Visual clutter
Disturbance of visual attention that is required for the driving task (e.g. looking at road signs) due the visual attraction of billboards.

Summary

Roadside advertising is, by its nature, designed to capture the attention of road users. Because humans have limited attentional resources it is therefore possible that such advertisements could hamper the safe execution of the driving task. The aim of this systematic literature review is to summarise findings from existing research on the impact of roadside advertisements on distraction and road safety (with a specific focus on digital advertisements).

An adapted version of the SEEV (Salience, Effort, Expectancy, Value) framework about visual attention of road users (Horrey, Wickens, & Consalus, 2006) was used to structure the findings. The factor of 'Luminance' was added to the SEEV-framework and the existing factor of 'Value' was expanded. These changes were made, respectively, to ensure that the issues of glare and billboard content were considered along with salience, the effort required from drivers, and the impact of expectancy.

Fifty studies were identified about the effects of roadside advertisements on crash risk or road user behaviour. Forty-nine of these studies were about drivers and one was about motorcyclists.

Five studies examining the association between crashes and roadside advertisements were found, although the findings do not allow firm conclusions to be drawn. In one study an increase in the number of crashes was found near billboards and in the four other studies no change was detected. However, the literature suffers from at least two limitations. One issue is that existing studies may lack statistical power. Because crashes are rare events and the stretches of road on which a billboard could contribute to a crash are short, the included numbers of crashes in such studies are mostly small, and therefore require many observations to detect any changes. Another issue is research design. Three of the five studies were before-and-after-studies (the crash rate before the placement of billboards and the crash rate after) and in two studies a comparison site was also included. A before-and-after-study with a comparison site is a stronger research design than a before-and-after-study without such a group. There were two before-and-after-studies with what appeared to be sufficient statistical power and a comparison site. In one of them an increase of crashes near digital billboards was found and in the other no difference was found.

Approximately half of drivers do not look at billboards when they pass them. However, drivers look more often and for longer at so called static digital billboards that display various static advertisements in sequence, when compared with traditional static billboards. The moments during which advertisements switch seem to be particularly distracting. Video billboards (digital billboards that display constantly moving images) attract the most attention. Drivers more often look at billboards at street level than at raised level but when they look at billboards at raised level they tend to look for longer. Young novice drivers are inclined to look at static digital billboards and video billboards the most. Although drivers rarely look for more than two seconds at a billboard, they sometimes do, especially when it is a static digital billboard or a video billboard. Given that there is strong evidence that long glances at objects outside the vehicle (and away from the road) increase crash risk substantially, this finding may be a cause for concern.

There is quite strong evidence that lane keeping deteriorates when drivers look at billboards. Billboards do not seem to have a strong impact on speed. In some studies, headways were found

to get shorter, in particular when drivers pass static digital billboards and video billboards. This may be dangerous because response latencies are longer when drivers look at billboards, and shorter headways mean that safety margins may be decreased even further. Drivers also more often overlook road signs and tend to forget to signal when they change lanes near billboards. The content of what is displayed on billboards does not seem to influence driving behaviour very much. What is displayed on the advertisements (arousing pictures and texts) influences decision making and driving performance only slightly. However, more research is needed to assess the effect of emotion-laden pictures and text on driving behaviour.

The less demanding the driving task is, the more drivers let their eyes wander to task-irrelevant objects. It seems that most drivers are able to regulate adequately the attentional resources the driving task requires. However, in traffic the task demands can suddenly increase and critical events (e.g. a lead vehicle that suddenly brakes) may not always be properly anticipated. In those circumstances looking at billboards could have detrimental effects on safety.

In most field studies no difference was found in gaze behaviour at illuminated billboards during day and night. This does not mean that such billboards do not have an impact on driving at night. Most jurisdictions regulate the amount of light billboards are allowed to emit. The illuminated billboards drivers passed at night in these field studies most probably were in compliance with these regulations. Illuminated billboards definitely can cause glare. In one simulator study it was found that the more light a digital billboard emitted the longer were driver response latencies to acute road hazards.

1 Introduction

Roadside advertising is intended to capture the attention of road users. Most of the time these advertisements are billboards that road users can see while they drive, ride, or walk on public roads, and that promote a product, event or activity. It could be that due to particular features of these billboards (e.g. size, moving images, luminance, content, et cetera) they capture so much attention of road users that they impede the safe execution of the traffic task. If so, they can contribute to the occurrence of road crashes.

ADVERTS is a research project that aims to compile recommendations for minimising distraction from roadside billboards - with a special focus on static digital billboards and video billboard - so that they do not interrupt the safe execution of the driving task. The current report forms the theoretical basis of these recommendations. It describes what has been reported in the scientific literature about the distraction of road side advertising devices and their effects on road safety. The parallel analysis of existing guidelines or regulations in European countries and the future trends in roadside advertising (Boets, Vandemeulebroek & Daniels, 2018) ensures that the recommendations are optimally aligned to current practices, while taking account of likely developments in roadside advertising techniques.

The current report starts with a brief introduction about the concepts of attention and distraction in relation to the traffic task (Chapter 2). After this introduction, the SEEV-model (Horrey et al., 2006) of visual attention in relation to the driving task is presented (Chapter 3). This model distinguishes several features that help to determine to what extent a roadside billboard is likely to attract attention and, hence, the extent to which it is distracting from the driving task. It functions as a framework for the discussion of the studies about particular features of roadside advertising devices and their effects on road safety (Chapter 4). Subsequently, the main findings from the literature are summarised and structured in the theoretical SEEV-model (Chapter 5). Finally, the report presents the overall conclusions about the effect of roadside advertising on road safety (Chapter 6).

2 Introducing the concepts of attention and distraction

2.1 Attention

Attention is crucial for safe traffic participation. Drivers and other road users have to monitor the developing road and traffic situation constantly. They also have to monitor the status of their own vehicle (e.g.: ”Am I driving not too fast?”) and they have to monitor their own status (e.g.: ”Am I still attentive?”). Besides this they have to take decisions and to execute actions such as steering, operating the pedals, in order to drive safely. All of this requires attention.

How much attention is required depends on the complexity of the road and the traffic situation, the weather conditions, the experience of the driver, the speed at which the driver is traveling, and the task demands of the vehicle (some vehicles are more demanding to drive than others). For experienced drivers, the basic tasks involved in driving appear to be almost as natural as walking. When experienced drivers drive in a familiar car, on familiar roads in not too dense traffic, the execution of the driving task requires not much attention (e.g. Mader et al., 2009). Nonetheless, the traffic situation, even in a quiet situation, can change rapidly. Drivers need to spot cues that predict that the traffic situation may develop into a hazardous situation (i.e. one in which the driver needs to take action to avoid a collision) so they can anticipate and avoid such occurrences. This continuously requires at least a basic level of attention.

The assumption is that experienced drivers can drive almost effortlessly, requiring relatively little attention, because they make use of schemata (Norman & Shallice, 1986). Schemata is plural of schema in Greek. At its lowest level a schema is a mental representation of a sequence of well learned actions. They help to perform the appropriate actions when particular circumstances arise. When for instance, a driver approaches an intersection and the traffic light turns red, the schemata for braking will be activated in the brain and will help the driver to perform the sequence of actions without too much mental effort. Low level schemata can be combined in a high level schema. These high level schemata are mental structures that organise our knowledge and enable us to make assumptions about what we perceive. They help us to cope with the world without too much mental effort. Schemata influence our selective behaviour, as we are more likely to notice or react to things that are anticipated by our schemata. The highest level schemata are called 'scripts' (Abelson, 1981; Schank & Abelson, 1977). One such script could be 'the driving along a motorway' script. This script is a conceptual structure of how to behave and what to expect when driving on a motorway. For example, driving at a relatively high speed in the same direction as the other vehicles, and no pedestrians that cross the road, no oncoming vehicles.

Groeger (2000) has described how schemata, and consequently the required attention, could function while driving. Citing theories of attention and the functioning of the brain developed by Posner and Petersen (1990) and by Stuss, Shallice and Picton (1995). Groeger distinguishes between many different aspects or types of attention. He assumes that drivers have to sustain attention, focus attention, share attention, switch attention, and suppress attention for objects and events that are irrelevant, prepare for attention in case of intended actions in the future, and to pay some attention to set a script (e.g. driving along a motorway). The examples given by Groeger are:

– Drivers *sustain* attention by keeping schemata activated for events that occur only occasionally. This can for instance be a lead vehicle that brakes suddenly. When drivers are prepared for this event, by keeping this schema latently activated, they will respond faster than when they are completely surprised by the event.

- When drivers are on a busy stretch of motorway and drive rather fast, they have to *focus* (concentrate) on what the traffic ahead is doing, e.g. weaving between lanes or braking.
- If drivers are talking to, for example, a passenger, they have to *share* their attention between the driving task and the conversation task.
- Drivers have to monitor the traffic situation ahead, but also the traffic situation behind. They *switch* their attention from the traffic situation ahead to the traffic situation behind by using the rear-view mirrors.
- When talking to a passenger, drivers have to *suppress* their inclination to make eye-contact with the passenger as they have to keep their eyes on the road.
- All the time drivers are driving on the motorway they have to be *prepared* to take actions when they see the sign of the required motorway exit. Being prepared to leave the motorway also means that when approaching the exit, drivers have to suppress their inclination to overtake other vehicles.
- When starting to drive on the motorway drivers have to *set* the 'driving along a motorway' script in order to enable them to select the proper underlying schemata in certain situations.

The key thing to note is that when road users drive, ride or walk, attention is required in very many ways. The overall workload may be relatively low due to the use of schemata, but a subtle disturbance in the interplay between these many types of attention can have adverse effects on the execution of the driving task. It could be that distraction by roadside advertisements can cause such a disturbance.

2.2 Distraction

Because experienced drivers automatically apply elaborated schemata, the driving task does not require much attention when the road and traffic situation is not complex. In these circumstances there is a spare attentional capacity and drivers often let their eyes wander to objects outside the vehicle (Crundall, Van Loon & Underwood, 2006). According to Wickens (2008) everyone has limited attentional resources. Attention can be distributed to more than one task simultaneously, but only when the demands of the tasks involved are low and when the tasks are very different. For example, experienced drivers can superficially listen to music and drive at the same time, at least when the road and traffic situation is not very complex. However, when listening to music gets too demanding and/or the workload for the driving task increases, these two tasks can no longer be combined. That is to say that due to the secondary task (in this example listening to music) drivers might no longer sufficiently sustain attention, focus attention, share attention, switch attention, suppress attention or prepare attention in the ways required to remain safe. In other words, they are distracted due to the secondary task. Lee, Young and Regan (2008) define driver distraction as:

> "*A diversion of attention away from activities critical for safe driving toward a competing activity*."

Distraction has many different relevant elements that have to be considered (see Table 2.1):

- Source: The source of distraction can be an object, such as a billboard, a person, such as a passenger or a pedestrian on the pavement, an event, such as a low flying airplane that is landing, or an activity of the driver, such as mobile phone use while driving.
- Location: The source of distraction can be within the driver, for example when the driver is absorbed in thought or is daydreaming. The source can also be inside the vehicle, such as a wasp in the car or crying children in the back, or outside the vehicle, such as a billboard.
- Intentionality: The driver might be compelled to pay attention to the source because of its salience, e.g. a very bright external object, or the driver might voluntarily choose to pay attention, such as calling someone with a mobile phone.
- Process: Due to distraction, attention for the traffic task can get disturbed, attention can become insufficient because attention is diverted to other activities, or attention can get misallocated within the traffic task.
- Outcome: The outcome of distraction can be described in terms of impaired performance of the driver, such as late responses (e.g. braking and/or swerving) when an acute threatening situation arises, or in terms of impaired mental capabilities of the driver, such as diminished situation awareness, diminished hazard anticipation, and degraded decision making. The outcome can also be described in terms of car performance, such as speed disruptions and poor lane keeping. Finally, the outcome can be an increase in crash rate.

Table 2.1. Elements of distraction (Lee et al., 2008).

Source	***Location of Source***	***Intentionality***	***Process***	***Outcome***
Object Person Event Activity	Internal activity (e.g. daydreaming) Inside vehicle Outside vehicle	Compelled by source Driver's choice	Disturbance of control Diversion of attention Misallocation of attention	Delayed response Degraded longitudinal and lateral control Diminished situation awareness Degraded decision making Increased crash risk

Furthermore, a distinction is made between visual distraction, such as distraction caused by a digital billboard, auditory distraction, such as a ringing mobile phone, biomechanical distraction, such as manually adjusting the radio volume, and cognitive distraction, such as being lost in thought (Ranney, Mazzae, Garrott, & Goodman, 2000).

In the case of billboards, the source is an object that is located outside the vehicle. We can conceive of billboards attracting the driver's attention by their appearance (i.e. a driver is compelled by the source to look) and of drivers who intentionally choose to look at them, for instance, when a driver is hungry and is searching for a billboard of a restaurant. This shift of attention away from the driving task may result in a delayed response, for instance, late braking when a lead vehicle suddenly brakes, degraded longitudinal and or lateral control, diminished situation awareness, degraded decision making. All these negative influences on the execution of the driving task may result in an increased crash risk.

3 Framework for distraction by roadside advertising

Not all objects attract the same amount of attention. Wickens and colleagues have developed a model that can be used to understand why certain objects are more distracting than others. Their model predicts how observers, for instance drivers, will allocate their visual attention to different areas of interest in their environment (Horrey et al., 2006; Wickens, Helleberg, Goh & Horrey, 2001; Wickens & Horrey, 2008). According to this model, scanning is guided by the influence of four factors: Salience, Effort, Expectancy, and Value (SEEV).

- *Salience* is about being compelled to look for example at billboards because of their appearance. An object has visual salience or conspicuity when it contrasts highly with its background. Size, flashing lights, sudden changes of colours and motions increase visual salience. Large illuminated digital billboards in the dark with changing colours and moving images are more salient than small traditional static billboards that are not illuminated. Salience is not only visual. Sudden sounds and vibrations can also attract attention.
- *Effort* is an inhibitory component that discourages observers from scanning between two locations that are far apart. When for instance drivers need to turn their head to read an advertisement, they will be less inclined to take notice of that advertisement than when the advertisement is straight ahead. Effort is also related to workload. When drivers have to allocate much attention to the driving task, for instance because the road and traffic situation is complex, they will be less inclined to look at billboards. Furthermore, studies have shown that the breadth of visual scanning tends to decrease when mental workload increases (Crundall, Underwood & Chapman, 2002). This means that billboards that are further away from the forward road will be less likely to be noticed when drivers have to concentrate on the traffic ahead.
- *Expectancy* is about the tendency of drivers to scan for information that is relevant for the task at hand. For instance, they may search for a signage board that indicates that they have to leave the motorway in order to reach their destination.
- *Value* accounts for the fact that people tend to seek for the information that is most relevant to the tasks they value. For example, when a driver is hungry and is looking for a place to eat, he or she will be more likely to scan for advertisements of restaurants than would otherwise be the case.

Furthermore, the model distinguishes between bottom-up and top-down induced fixations (glances at an object). A fixation induced by visual salience is called bottom-up selection (Itti & Koch, 2001; Parkhurst, Law & Niebur, 2002) and a fixation induced by cognitive salience (e.g. looking in a direction because one is expecting that goal relevant information can be found in that direction) is called top-down selection (Henderson, Brockmole, Castelhano, & Mack, 2007). Different brain circuits are probably active when a fixation is induced top-down and when a fixation is induced bottom-up (Hahn, Ross & Stein, 2006). For example, drivers might simply have their attention captured by a billboard because of its visual salience, and not be able to help themselves looking. Otherwise, drivers might deliberately scan for information if they are looking for a petrol station (Henderson et al., 2007). Salience and Effort are bottom-up processes of visual attention and Expectancy and Value are top-down processes of visual attention. Figure 2.1 illustrates this.

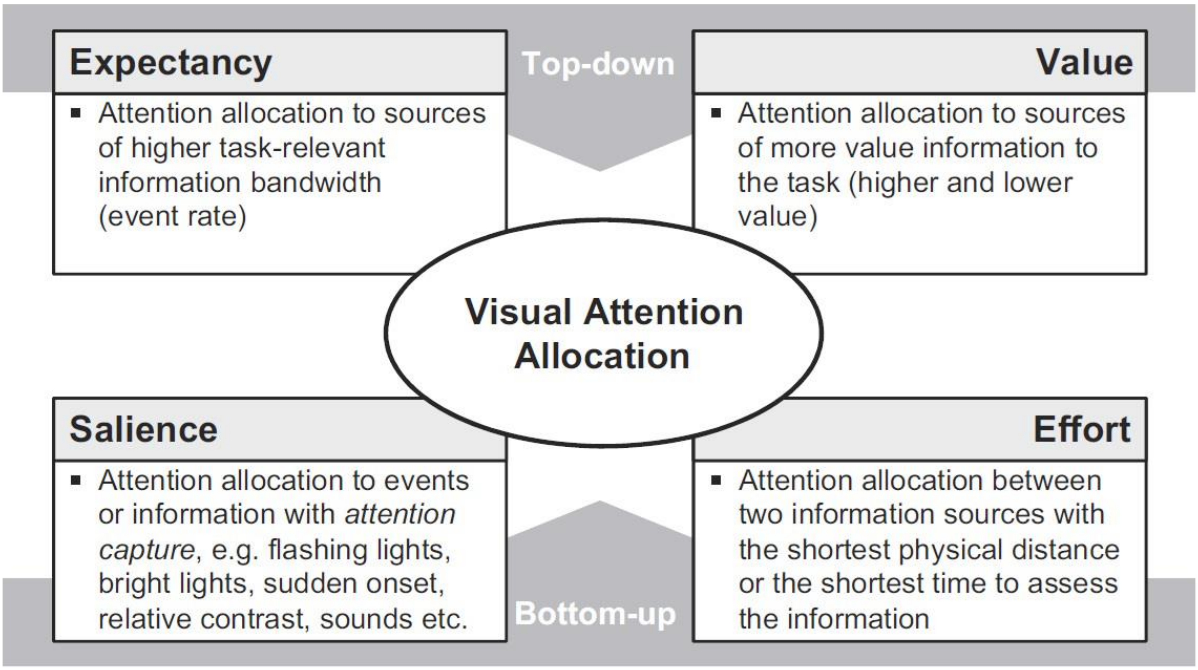

Figure 2.1 *Determinants for visual attention allocation in the SEEV-framework (Source: Werneke & Vollrath, 2012).*

The SEEV-framework explains why road users will be inclined to look at billboards and when. However, the SEEV-framework does not explain the possible deterioration of the traffic task once the billboard has captured the attention of the road user. Three factors are particularly relevant in this respect.

1. The content of a message on the billboard can arouse the driver or change his/her mood. It is a well-known fact that emotions can affect the execution of the driving task (e.g. Mesken, 2006).
2. The text on the billboard can invite drivers to do things that will affect the safe execution of the driving task. A billboard can for instance display the text: ”Call us now and win xxx Euro: dial xxxxxxxx”. Dialling a number on a mobile phone while driving increases the crash risk substantially (Dingus et al., 2016).
3. (Digital) billboards can be highly illuminated. During hours of darkness high levels of luminance can dazzle drivers, especially older drivers who are known to be more sensitive to glare.

Within the current study we consider the two aspects related to the billboard messages to belong to the SEEV-factor Value. In order to deal with the issue of glare we extended the model with the factor Luminance.

In summary, factors related to **Salience** are:

- The presence of moving images or text in advertisements
- Other movement such as rotating advertisements

- Lighting, colour and contrast with background[1]
- Exposure time of an advertisement on a static digital billboard
- Transition from one advertisement to the other on static digital billboards

Factors related to **Effort** are:

- Position of the advertisement in relation to the forward view of the driver
- Size of advertisement
- The visual clutter in the forward view of drivers (e.g. buildings, other billboards, and road signs that surrounds the advertisement)
- Font size of the letters on billboards
- The amount of text on a billboard
- The composition of pictures and text on a billboard
- The traffic density at the spot of the advertisement
- The complexity of the traffic situation at the spot of the billboard.

Factors related to **Expectations** are:

- Do the advertisements look like road signs?
- Are the advertisements at spots where drivers search for relevant information for the safe execution of the driving task?
- Do the advertisements (partly) block the view on information that is relevant for the safe execution of the driving task?
- Does a billboard refer to information that will be on a next billboard along the road? For example “See our next billboard along this road what we can offer you...”

Factors related to **Value** are:

- Content of message, pictures and or texts that may evoke emotions
- Content related to current goals of the driver (for example food, drink)
- Text that encourage drivers to engage in distracting activities (e.g. using their mobile phone).

Factors related to **Luminance** that are not related to salience:

- Does the illuminated billboard/object cause glare?
- Does the brightness of the illuminated billboard make unilluminated road signs almost invisible?

The five categories of this extended SEEV-framework and the factors within each category will be used as a framework for reviewing the literature (see Chapter 5).

[1] The luminance of a billboard determines how salient the billboard is. Bright billboards in the dark attract attention but they can also cause glare. Glare caused by luminance is not a factor of salience.

4 Results of the literature review

4.1 Identification and classification of relevant literature

By means of a systematic literature search we aimed to identify the studies that specifically looked into the effect of roadside advertising on road safety. The following queries and search terms were applied:

(adverti* OR billboard*) AND (driv* OR rid* OR walk*)

OR

(adverti* OR billboard*) AND (disract* OR inatten*)

OR

(adverti* OR billboard*) AND (safety OR traffic OR crash* OR accident*)

Databases searched were the SCOPUS database of Elsevier (https://www.scopus.com), Google Scholar, and the SWOV-library (http://library.swov.nl). After having deleted the 'false positives' (e.g. studies about marketing), 50 studies were identified.

The identified studies appeared to differ substantially with regard to what they measured to assess the effects of roadside advertising. The 'final' outcome measure or dependent variable is crash rate; i.e. Are there more crashes at spots where (digital) billboards are present than at similar spots without (digital) billboards? There are only a few studies that looked at the effect of billboards on crash rate. These are discussed in Paragraph 4.2.

Dependent variables can also be a less direct measure, e.g. a Safety Performance Indicator (SPI). SPIs are road user behaviours that are known to contribute to the occurrence of crashes. Eye glances at billboards and other gaze behaviours are one obvious outcome which are likely to be related to crashes, for example when a driver looks at a billboard she or he cannot at the same time observe the road and traffic situation. Several studies used this measure and they are presented in Paragraph 4.3.

Other SPIs relate to actual road user behaviour and include response times to sudden driving events and longitudinal and lateral vehicle control. Most studies are at this level and are described in Paragraph 4.4.

Some studies focused on the effect of roadside advertising on situation awareness of drivers. Drivers with good situation awareness permanently know what is going on around them (Gugerty, 1997; Salmon, Stanton, & Young, 2012). These drivers are also good in hazard perception (Horswill & McKenna, 2004). Good situation awareness also means that drivers know that in particular circumstances other road users can be on a collision course but that they are not yet visible because something blocks their view. Paragraph 4.5 describes the results of this type of studies.

Finally, billboards can also influence decision making due to the emotions that are invoked by what is displayed on a billboard. For instance, one can investigate if drivers start to use their mobile phone after they have passed an advertisement with a phone number on it. The effects the content of the advertisements have on driving performance are discussed in paragraph 4.4.

Four studies were found in which evaluation studies on the effect of road side advertisement were reviewed (Brijs, Brijs & Cornu, 2014; Decker et al., 2015; Wachtel, 2016; Ziakopoulos, Theofilatos, Papadimitriou & Yannis, 2017). These are discussed in Paragraph 4.6.

4.2 Studies on crash risk

Five studies were found in which crash data were analysed. Three of these studies are published in peer reviewed journals (Izadpanah, Omrani, Koo & Hadayeghi, 2014; Smiley et al., 2005; Yannis, Papadimitriou, Papantoniou & Voulgari, 2013), one is a conference paper (Gitelman, Zaidel & Doveh, 2012), and one is a report by a consultant that conducted the research by order of an interest group of road side advertisers (Tantala & Tantala, 2010). The studies looked at different types of billboards. Billboards can be:

– Traditional *static billboards* that can be illuminated, e.g. by spotlights (see Figure 4.1).

Figure 4.1 *Example of a traditional static billboard.*

– *Static digital billboards,* i.e. billboards that most of the time are composed out of LED screens or are one big LED screen that emit light and that display a static advertisement for some time which is then replaced by another static advertisement (see Figure 4.2).

Figure 4.2 *Example of a static digital billboard. The large LED screen emits light but while an advertisement is displayed on the screen for a couple of seconds nothing moves in the advertisement.*

– *Video billboards*, billboards made out of LED screens or one big LED screen on which videos or animations are displayed. Video billboards are as static digital billboards but the displayed advertisements are not static (see Figure 4.3).

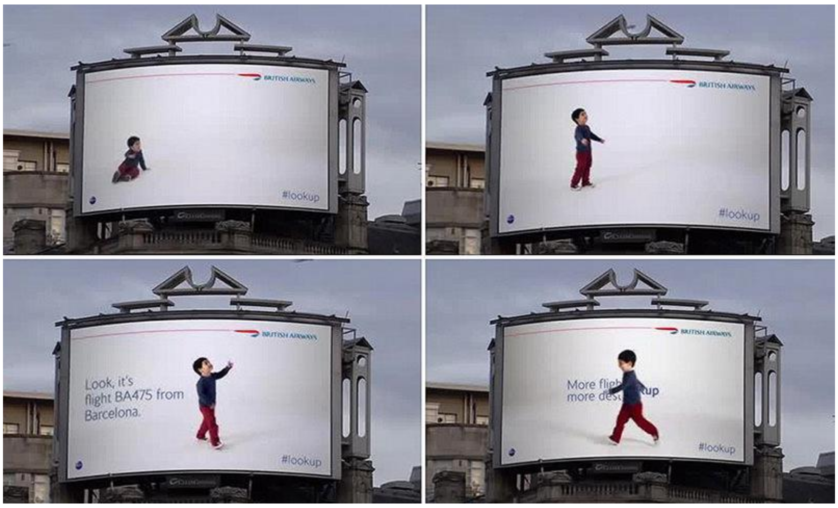

Figure 4.3 *Example of a video billboard. The boy in the advertisement walks.*

Gitelman et al. (2012) and Yannis et al. (2013) do not specify what type of billboards their studies covered. The studies of Smiley et al. (2005), Izadpanah et al. (2014), and Tantala and Tantala (2010) were about static digital billboards. In the study of Tantala and Tantala (2010) the exposure time of a single advertisement on the digital billboards was 10 seconds. In the studies of Izadpanah et al. (2014) and in Smiley et al. (2005) the exposure time of a single advertisement was not specified.

All five studies were before-and-after studies. They all addressed a question of the form 'What was the crash rate before billboards were placed along a certain stretch of road and what was the crash rate on that same stretch of road after the placement of billboards?' In order to control for confounding factors, in three of the studies a comparison stretch of road was included in the analysis (Gitelman et al., 2012; Izadpanah et al., 2014; Smiley et al., 2005).

4.2.1 Conclusions on crash risk

Only the study of Gitelman et al. (2012) found a statistically significant increase of crash rate near billboards. In this study the static billboards along a certain stretch of road were visible during a two year period and then they were covered for a period of one year. After adjusting for traffic volume, the overall crash rate in the period with covered billboards was 60% lower than in the period with visible billboards. For injury crashes (including fatal crashes) this decline was 39% and for property damage only crashes it was 72%. In the four other epidemiological studies no effect on crash rate was found. This means that based on the existing evidence, the effect of billboards on crash rate is inconclusive. On the basis of the results it cannot be concluded that (digital) billboards increase crash risk nor can it be concluded that they have no effect on crash risk at all.

Crashes are rare events. From a societal point of view there are of course far too many, but for statistical analyses there are insufficient crashes when only the crashes in the vicinity of billboards over a limited period of time can be included in the analysis. Long stretches of road were included in the study of Yannis et al. (2013), and the study of Tantala and Tantala (2010) was over a long period of time (88 months). However, these two studies were before-and-after studies without comparison roads. This means that these studies are strong with regard to the number of crashes that were included in the analysis, but weak in controlling for confounding factors that vary with time (Elvik, 2002). The study of Smiley et al. (2005) seems to lack statistical power (small sample size), the four other studies have sufficient statistical power. Of these four studies two had a strong design (before-and-after study with a comparison site). Of these two studies one found an increased crash risks near static digital billboard (Gitelman et al., 2012) and the other not (Izadpanah et al., 2014).

4.3 Studies on gaze behaviour

4.3.1 Gaze behaviour and crash risk in general

A second set of studies looked at the gaze behaviour of drivers. This is a relevant SPI, because there is an association between not looking at the road- and traffic situation, and crash risk. The large scale Naturalistic Driving study “SHRP 2” revealed that the factor “extended glance duration to external object” had a crash Odds Ratio (OR) of 7.1 (95% Confidence Interval (CI): 4.8-10.4). It also revealed that these extended glance durations to external objects occurred during 0.93% of the driving time observed (the prevalence) (Dingus et al., 2016). An OR of 7.1 can, in this situation, be interpreted as a Relative Risk (RR) of 7.1[2]. meaning that people who demonstrate

[2] In many studies the OR is presented and not the RR because it is possible to calculate OR and most of the times it is not possible to calculate RR. However, technically Odds Ratio is not the same as Relative Risk. The odds of an event occurring (in this case a crash) is equal to the probability of the event occurring divided by the probability of it not occurring. Relative risk is a ratio of the probability of an event occurring in the exposed group (crashes of drivers that pass billboards) versus the non-exposed group (crashes of drivers that do not pass billboards). When events are rare, OR and RR are almost the same. Crashes are rare and thus the calculated Odds Ratio can be interpreted as the not calculable Relative Risk. The 95% Confidence Interval (CI) that ranges from 4.8-10.4 means that the best estimate is the OR (interpreted as relative risk) is 7.1 and that it is for 95% certain that the OR will be anywhere between 4.8 and 10.4.

the behaviour are just over seven times as likely to be in a crash as those who do not. In this case it means that when drivers gaze at an object outside the vehicle for a long time, their chance to get involved in a crash is 7.1 times the chance to get involved in a crash when they would have kept their eyes on the road.

Dingus et al. (2016) did not specify what ‘extended glances’ are. They also did not specify what the external objects were. In one of the background reports about the SHRP 2 study it is stated that a glance before a crash was considered as extended when during the 6 seconds before a crash, the total dwell time on irrelevant objects for safe driving (e.g. the dwell time on a billboard or something inside the vehicle such as a smartphone) was at least 2 seconds (Trent et al., 2015). The OR depends on how much longer than 2 seconds the eyes were not at the forward path of the car and when exactly within the 6 seconds time frame before the crash, the extended glances were made. When for instance the eyes were not at the forward path in the period from 5 to 3 seconds before the crash, the OR was 5.7 and when the eyes were not on the road from 3 seconds to 1 second before the crash, the OR was 13.6 (Trent et al., 2015).

In another Naturalistic Driving study involving only young drivers a slightly different analysis was made (Simons-Morton, Guo, Klauer, Ehsani & Pradhan, 2014). When in the 6 second period before a crash or near crash the driver’s eyes were not on the forward path for over 1 second compared with less than 1 second, the OR was 1.7 (95% CI: 1.3-2.2). When comparing more than 2 seconds with fewer than 2 seconds the OR was 3.8 (95% CI: 2.6-5.6). The comparison for more than/fewer than 3 seconds, 4 seconds and 5 seconds gave OR values of 6.0 (95% CI: 3.4-10.7), 7.2 (95% CI: 3.3-15.7), and 8.9 (95% CI: 3.3-24.1) respectively. The results of this study imply that for young and inexperienced drivers even dwell times of just over one second away from the forward path can increase crash risk. Whether this will be the case or not depends of course on the actual road and traffic situation. When the traffic density is low and the situation is not very complex, it is not very likely that a glance of one second away from the forward path will result in a crash. However, in complex traffic situations in dense traffic a glance of just over one second off the road can indeed result in a crash. The study of Simons-Morton et al. (2014) is about young inexperienced drivers only. It could be that glances away from the forward road way of just over one second are less devastating for older and more experienced drivers. However this ‘intuitive’ notion may not be correct; there is some suggestion that the advantages that more experienced drivers show in safety-critical skills such as hazard perception can, if anything, be even more prone to interference from distraction due to their effortful processing nature (see for example McKenna & Farrand, 1999). Direct research into this topic may be warranted.

4.3.2 Effects of billboards on gaze behaviour

Eleven studies on the impact of billboards on gaze behaviour were found. In all except one (Herrstedt, Greibe, & Andersson, 2013) use was made of a non-intrusive remote eye tracking device. In the study of Herrstedt et al. (2013) the face of the driver and the forward view was filmed simultaneously. Based on these two recordings the researchers assessed whether drivers looked at billboards or not. Of the eleven studies on gaze behaviour, six were field studies (Belyusar, Reimer, Mehler, & Coughlin, 2016; Dukic, Ahlstrom, Patten, Kettwich, & Kircher, 2013; Herrstedt et al., 2013; Herrstedt, Greibe, Andersson & la Cour Lund, 2017; Misokefalou, Papadimitriou, Kopelias & Eliou, 2016; Perez, Bertola, Kennedy & Molino, 2011), four were simulator studies (Chattington, Reed, Basacik, Flint & Parkes, 2009; Garrison & Williams, 2013;

Megías et al., 2011; Stavrinos et al., 2016), and in one study participants watched videos that were filmed from a driver's perspective while their gazes were recorded (Crundall et al., 2006). Four studies were about static digital billboards only (Belyusar et al., 2016; Dukic et al., 2013; Herrstedt et al., 2017; Perez et al., 2011). In two studies a comparison was made between traditional static billboards and static digital billboards (Chattington et al., 2009; Stavrinos et al., 2016). In the study of Chattington et al. (2009) video billboards were also included. One study was about traditional static billboards only (Garrison & Williams, 2013) and three were about all types of billboards (Crundall et al., 2006; Herrstedt et al., 2013; Misokefalou et al., 2016). Different types of road were included in the studies. However, most roads were motorways. An exception is the study of Chattington et al. (2009) in which all roads were urban roads.

The field studies:

In the six field studies, participants tended to drive in an instrumented vehicle equipped with a non-intrusive eye tracker. Participants drove a fixed route that took them past several billboards. The nature of the study was not told to the participants; the research question was essentially 'do participants look at billboards and when they do so, how long do they look at them?' Most of the time differences in gaze behaviour between traditional static billboards and static digital billboards were also analysed. None of the field studies included video billboards.

The first field study with an advanced eye tracking system on the open road was conducted by Perez et al. (2011). The authors compared glance behaviour during a road section with no billboards ('control') with glance behaviour on a similar road section with digital billboards and traditional static billboards in two cities. Data were collected during the day and night and across different road types. The authors concluded that the presence of digital billboards was not associated with "unacceptably long glances away from the road". This study was commissioned by the Federal Highway Administration (FHWA) in the United States, never appeared in a peer reviewed journal, and has been strongly criticized (Wachtel, 2015). The study has many flaws (e.g. low quality eye tracking) and the general conclusion (no unacceptably long glances at digital billboards) was not supported by the results. Participants did in fact gaze more at digital billboards than at traditional static billboards, despite the fact that the digital billboards were smaller in size than the traditional equivalents.

In the first field study of Herrstedt et al. (2013) gaze behaviour at static traditional billboards was analysed. Drivers looked at 69% of the traditional static billboards they passed. 82% of the glances at these billboards lasted less than 1 second. 16% were between 1 second and 2 seconds, and 2% were longer than 2 seconds. However, because no eye tracking equipment was used, the measurement of gazes at billboards was not very accurate. In their second study Herrstedt et al. (2017) made use of advanced eye tracking technology and analysed glance behaviour at digital billboards only. The exposure time, i.e. the time a billboard was in sight of the participant and the participant was able to read what was on that billboard, was approximately 6 seconds. In approximately 60% of all the drive pasts, participants had a quick look at a static digital billboard. In 15% of all the drive pasts the dwell time 2 s or more. Dukic et al. (2013) found that for more than half the billboards, participants did not look at all. However, they more frequently looked at the static digital billboards than at traditional static billboards and road signs. When they looked, the gazes were also longer at static digital billboards than at traditional static billboards. However, a dwell time of greater than 2 seconds at digital billboards rarely occurred (0.08% of the dwell times at digital billboards). There were no differences in gaze patterns at static digital billboards during day time and during night time. Misokefalou et al. (2016) found that when drivers looked at advertisements (both traditional static billboards and static digital billboards) this was on average for 0.86 seconds; only 29% of the dwell times on advertisements were over 1 second in duration. Finally, Belyusar et al. (2016) found that although glances of 2 seconds and more rarely occurred (around 1% of the glances), young drivers tended to make more long glances at billboards than older drivers, especially around moments that the advertisement switched at the digital billboard.

The laboratory studies:

Gaze behaviour was analysed in four simulator studies and in one study in which participants watched videos that were filmed from the driver's perspective while their gaze behaviour was recorded. In the four simulator studies gaze behaviour was analysed in combination with driving performance such as lateral position in the lane, speed, steering wheel reversal rate, headway to a lead-vehicle. In this section, only the results of the eye tracking recordings are discussed.

In the study of Chattington et al. (2009) participants drove in an urban area with traditional static billboards and video billboards. Video billboards were digital billboards with constantly moving images on the screen. These video clips lasted around 6 seconds, and were played on repeat. Billboards (both the traditional static billboards and the video billboards) could appear on the left side, the right side, or straight ahead of the driver (e.g. on top of a gantry). All billboards were placed around three to four meters above street level. Billboards at street level such as advertisements on bus stops were not included. Some billboards could already be seen from far away. These were billboards with a long exposure duration of 6 seconds and more. Due to buildings and curves some were visible for around 4 seconds (intermediate exposure duration), and some were only visible for around 2 seconds (short exposure duration). Overall, drivers looked at video billboards for 12% longer than they did at static billboards, and on average made 34% more glances to video billboards. The findings were also dependent on the advert exposure duration. When drivers looked at a billboard, they looked equally long at a traditional static billboard and a video dynamic digital billboard when the exposure duration was long. When the exposure time was intermediate, they glanced longer at dynamic digital billboards than at static billboards. When the exposure time was short there was again no difference in glance duration between the two. Participants also looked more often and for longer at billboards of both types when they were straight ahead than they were placed on the left and the right side of the road.

In the simulator study of Garrison and Williams (2013), drivers encountered possible hazards (e.g. a pedestrian who due to the circumstances could cross the road without paying attention), passed traditional static billboards and passed traffic signs. They did this in two conditions. In the baseline condition they just drove without any secondary task and in the experimental condition they had a conversation with a passenger while they drove. The hypothesis was that in the experimental condition (talking with a passenger) drivers would concentrate on hazards and important road signs at the expense of looking at billboards. The results only partly supported this hypothesis. The mean number of fixations on the three categories (hazards, signs, and billboards) were lower in the distracted condition (talking with a passenger) than in the baseline condition, but there were no interaction effects. This implies that hazards, signs and billboards all received fewer fixations in the distracted condition. However, with regard to dwell time (the total gaze duration), an interaction effect was found. Dwell times were shorter in all three categories in the distracted condition but significantly more so for billboards and signs than for hazards. So when participants gazed at billboards while distracted, their total gaze duration at the billboards was significantly shorter than when not distracted, whereas when they gazed at hazards while distracted, the total gaze duration at those hazards was the same as when not distracted. This suggests that drivers were able to moderate their distraction for non-driving-critical targets, at least to some degree.

In the simulator study of Stavrinos et al. (2016) teenage drivers (16-19 year old), middle-aged adults (35-55 year old), and older drivers (65 and older) drove past traditional static billboards and static digital billboards. When a participant was in the direct vicinity of a static digital billboard, the advertisement on the billboard switched automatically. Glances of at least 2 seconds were very rare on both traditional static billboards and digital static billboards, but not for the youngest age group. The differences between static traditional billboards and static digital billboards were small. However, dwell time increased for teenage drivers and middle-aged adult drivers when the transition from one advertisement to the next on the static digital billboards was slow.

Finally, Crundall et al. (2006) investigated the influence the location of the billboard has on gaze behaviour. In their laboratory study participants watched video clips that were filmed from the perspective of a driver, while their eye glances were recorded. In these clips some of the advertisements were placed at street-level (e.g. on bus shelters) and some were placed at raised-level (around 3m above the ground). Drivers' eyes are most of the times directed towards the forward road view and within that view at the focus of expansion. The focus of expansion (FoE) is the fixed centre in optical flow when moving forward. From the FoE drivers scan more broadly horizontally than vertically (Underwood, Chapman, Brocklehurst, Underwood & Crundall, 2003) (see Figure 4.4).

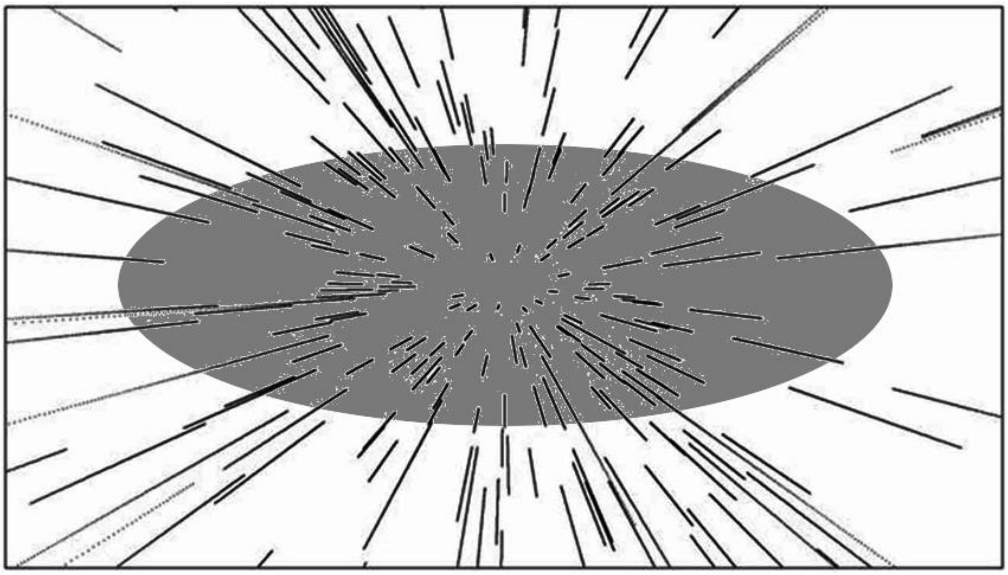

Figure 4.4 *Focus of Expansion (FoE) and area where drivers fixate the most (the size of the ellipse is indicative). The closer to the centre, the more fixations are made. However, drivers tend to scan more broadly along the x-axis of this centre than along the y-axis of this centre.*

Because drivers scan more broadly horizontally than vertically it was expected that advertisements at street-level (just within the ellipse in Figure 4.4) would be more often fixated than advertisements at raised-level (just outside the ellipse in Figure 4.4). This was indeed what the researchers found. However, when participants were asked to look for advertisements in the video clips, the advertisements at raised-level were better remembered than the advertisements at street-level.

The studies so far did not account for the contents of the advertisement. When the content of what is displayed on the billboard is not relevant for the road user, she or he will normally soon turn the eyes back to the road and traffic situation. This is probably the reason why dwell times at billboards mostly are brief. However, it could be that drivers keep on looking at billboards because what is displayed on the billboard is relevant for them and could affect their emotions. In a study with a motorcycle simulator, participants who were equipped with an eye tracker, passed affect-laden static billboards (Megías et al., 2011). These billboards could display something pleasant (e.g. a laughing baby), something unpleasant (e.g. an injured person), or something neutral (e.g. a spoon). More fixations were made and dwell times were longer when the billboards displayed pictures that were pleasant and unpleasant than when the displayed pictures were neutral. There was no difference in the number of fixations and dwell times between unpleasant and pleasant billboards.

4.3.3 Conclusions regarding gaze behaviour

It can be concluded that for approximately half the billboards drivers pass, they do not look at them at all. When they look, they rarely look at them for more than two seconds. However, they look more often and for a longer time at static digital billboards than at traditional static billboards. Video billboards with moving images seem to attract most attention. The closer the billboard is located near the forward road view of the driver, the more often drivers will look at the billboard. Billboards at street level are more often looked at than billboards that are placed a few meters above the ground. Drivers look less often at billboards when the task demands increase.

Although dwell times of 2 seconds and more do not occur very often, they do occur at least some of the time, and glances of 2 seconds or longer away from the forward roadway increase crash risk substantially. Even very short dwell times could conceivably increase crash risk when the road and traffic situation is complex (see e.g. Simons-Morton et al., 2014), and these shorter dwell times are still common. One also has to keep in mind that although dwell times of 2 seconds or longer are rare, they occur more often when drivers look at video billboards and at static digital billboards, especially around moments when the advertisement at the billboard switches. Dwell times are longer when billboards display affect-laden pictures. When the age of the driver is taken into account, it seems that young drivers tend to look more often and longer at static digital billboards around moments that a switch of advertisement takes place than at static billboards.

4.4 Studies on driving behaviour

A total of 12 studies were found that had looked at changes in driving behaviour in the vicinity of billboards. These were all simulator studies because subtle behaviour changes can accurately be measured in a simulator, but are difficult to measure in real traffic. In the next paragraphs we present the effects on speed, lateral control, headway, response time, and driving errors and violations. A final paragraph specifically looks at the effect of the contents of the advertisement on driving behaviour.

4.4.1 Speed

The results on changes in speed near billboards are inconclusive. Chattington et al. (2009) found that drivers lowered their speed slightly when drivers approached a billboard. This was more so when it was a video billboard and the time the billboard was visible was medium (approximately 4 seconds) or short (approximately 2 seconds). In contrast, Marciano and Yeshurun (2012) found that speed increased slightly when drivers passed static billboards. Bendak and Al-Saleh (2010) found in their study that there were more speeding violations in the vicinity of static billboard, but this effect did not reach statistical significance. Milloy and Caird (2011) did not find differences in speed when they compared speed in the baseline condition (no billboards), the condition with traditional static billboards, and the condition with static digital billboards.

4.4.2 Lateral control

With regard to lateral control the studies are unanimous: lateral control deteriorates slightly when participants pass billboards, i.e. drivers tended to swerve more in the vicinity of a billboard. Chattington et al. (2009) found that in particular video billboards deteriorated lateral control. The standard deviation of the lateral lane position (an indicator of swerving) increased when drivers approached these billboards when they were visible for a short period of time (2 seconds) and when they were visible for a medium period of time (4 seconds) but not when they were visible for a longer period of time (6 seconds). Young et al. (2009) found that the time spent out of lane and the number of lane excursions increased near traditional static billboards, especially when these billboards were located along rural roads. Bendak and Al-Saleh (2010) found that drivers tended to drift from lane near traditional static billboards.

4.4.3 Headway

On the question of whether participants drive closer behind lead vehicles when they pass billboards, the evidence is not conclusive. Milloy and Caird (2011) found that the minimum headway distance, the shortest distance between the front bumper of in this case the simulator car and the rear bumper of the lead vehicle, was shorter when participants passed static digital billboards than when they passed traditional static billboards. The difference in headway was also statistically significant between traditional static billboards and no billboards with the shorter headways when participants passed traditional static billboards. Bendak and Al-Saleh (2010) conclude that tailgating occurred more often near billboards than in the baseline condition (no billboards). However, this difference did not reach statistical significance. Young et al. (2009) did not find any difference in headway when participants passed billboards of any kind compared with the baseline condition (no billboards).

4.4.4 Response time

Do billboards cause an increase in response time to unexpected driving events such as a lead vehicle braking? Milloy and Caird (2011) found that participants took significantly longer to respond to a braking lead vehicle when they passed static digital billboards than when they passed traditional static billboards or did not pass a billboard at all (the baseline condition). They also found that in their simulator study more collisions with the suddenly braking lead vehicle occurred when drivers passed static digital billboards than when they passed traditional static billboards or did not pass a billboard at all. In this simulator study the advertisement on a static digital billboard always automatically switched when the vehicle approached. No other studies were found about response latencies near billboards. The study of Milloy and Caird (2011) indicates that in particular static digital billboards cause an increase in response time around moments of a switch from one advertisement to the other on these billboards.

4.4.5 Driving errors and violations

In the simulator study of Edquist, Horberry, Hosking, and Johnston (2011), billboards (a traditional static billboard or a static digital billboard) could be placed on the other side of the road where a road sign instructed drivers to change lanes. Did participants more often not change lanes when a billboard was present? And when they did change lanes, did they do so later in time at the presence of a billboard? More often, participants did not change lanes when a billboard was present. Of the 1152 times when participants had to change lanes, 62 times they did not do so and of these 62 times, 50 times were when a billboard was placed opposite the lane change sign. This difference was statistically significant. When participants did change lanes, they did so significantly later in time when a billboard was present. There was no difference between traditional static billboards and static digital billboards.

Bendak and Al-Saleh (2010) found that participants significantly more often crossed an intersection recklessly when a traditional static billboard was placed near that intersection than when there was no billboard. The authors do not define what they considered to be reckless crossing. Bendak and Al-Saleh (2010) also found that changing lanes in the vicinity of traditional static billboards occurred more often without signalling when there was no billboard.

4.4.6 Effect of content of advertisement on road user behaviour

The content of an advertisement can have an effect on the emotional state of the road user and the content of what is displayed on a billboard can for instance also activate drivers to execute certain dangerous actions such as dialling a telephone number. No studies were found about evocations on billboards to engage in distracting activities. However, some studies were found about affect-laden advertisements on driving behaviour. Megías, Di Stasi, Maldonado, Catena, and Cándido (2014) conducted a study with a motorcycle simulator in which participants encountered an intersection with an amber traffic light after just having passed a billboard. The depicted picture on that static billboard could be either pleasant, unpleasant, or a neutral. The content of the billboard had no effect on the decision to speed up or to brake at the amber traffic light. However, the displayed pictures had an effect on the tendency to take risks when also the moment of the decision to brake or to speed up was taken into account. The risk taking tendency (i.e. to speed up at the very last moment) was lower after having passed a negative advertisement compared with a positive and neutral advertisement.

In a simulator study by Chan and Singhal (2013) participants drove past a traditional static billboard that contained a single word and no pictures. This could be a negative word (e.g. stress), a positive word (e.g. joy) or a neutral word (e.g. clock). They measured several driving performance indicators just after having passed a billboard. These indicators were speed, lateral position, steering wheel reversal rate and steering wheel angle. The type of words only had an effect on speed. Drivers had lower mean speeds when there were emotional words (both positive and negative) compared with neutral words, and this slowing effect lasted longer when there were positive words. In a follow-up simulator study the researchers also had billboards with taboo arousing words (Chan, Madan, & Singhal, 2016). Results showed that taboo words captured the most attention. Interestingly, taboo words appeared to improved lateral control for a while.

4.4.7 Conclusions regarding driving behaviour

There is quite strong evidence that lateral control deteriorates when drivers look at billboards. They tend to drift slowly out of their lane. Looking at billboards doesn't seem to influence vehicle speed very much. However, there are some indications that headways get shorter in particular when drivers pass static digital billboards and video billboards. Close following is even more dangerous than in circumstances without billboards because there is quite strong evidence that drivers tend to respond (brake) later in time near static digital billboards and video billboards when a lead vehicle suddenly brakes. Drivers also more often overlook road signs and tend to forget to signal when they change lanes near billboards. The content of what is displayed on billboards does not seem to influence the driving behaviour so much. Although the content had minor effects on driving behaviour and the tendency to take risks, one has to keep in mind that studies about the displayed content were all simulator studies. It could be that drivers will behave somewhat differently when exposed to arousing pictures and text in real traffic.

4.5 Studies on situation awareness

Road users need to be aware of what is going on around them. At every moment in time they have to be able to detect the relevant changes in the road and traffic situation, comprehend what these changes mean, and predict how possible hazards can develop into acute threats that need to be anticipated (e.g. Crundall, 2016). Can billboards diminish situation awareness of drivers? Only one study was found in which this was investigated (Young, Stephens, Logan & Lenné, 2017). Participants in this study were instructed to maintain a continuous dialogue of their internal thoughts related to their journey. They had to verbalize these thoughts aloud. These included general thoughts about where they were positioning their vehicle and why; thoughts about the road environment, road condition, road signs or billboards, road signals, other road users, what they were doing, how that related to the driver and what actions they were taking and intended to take. All this was recorded while the participants drove a fixed route in real traffic that took them past traditional static billboards. Results indicated that the structure and content of drivers' situation awareness was not appreciably affected by the billboards. Drivers mentioned billboards when driving demand was low, such as when driving on a motorway with light to moderate traffic, in lower speed zones, or when stationary. However, when drivers were required to perform a manoeuvre or driving demands increased, drivers did not mention the billboards but mentioned subjects related to the driving task. This indicates that the participants in this study regulated the attention they paid to billboards.

4.6 Other studies and overview studies

4.6.1 Other studies

All studies reviewed so far examined distraction from billboards in real traffic or in a simulator. Marciano and Setter (2017) used a method which was designed instead to make advertisements the primary focus of attention. Participants watched static advertisements that were displayed on a monitor and had to answer questions about them, while they examined the advertisement, they had to execute a tracking task that was displayed to the right of the depicted advertisement simultaneously. This tracking task resembled the steering aspect of the driving task. Participants also had to identify a change of colour of a circle that was displayed in the upper right corner of the screen (a monitoring task). The question addressed was which type of advertisement deteriorated performance on the tracking task and the circle colour change identification task the most. There were five clusters of advertisements:

- Cluster 1: many words and a small picture,
- Cluster 2: many words and no pictures,
- Cluster 3: minimum of text (one or two words) in large font size,
- Cluster 4: large pictures with a minimum of text, and
- Cluster 5: large picture or many pictures and many text blocks.

The Cluster 5 billboards that the authors labelled as the 'loaded billboards', deteriorated the tracking task the most. The Cluster 4 billboards with large detailed pictures and only a few words, deteriorated the circle colour change identification task the most. The Cluster 3 type of billboards with a minimum of text in large font size affected the two secondary tasks the least.

The fact that billboards with only a few words interfered with the (surrogate) steering task the least was also found in a simulator study by Schieber, Limrick, McCall, and Beck (2014). In their study the billboard contained 4, 8 or 12 words. Participants drifted gradually away from the centre line while they read the billboard and then re-established their course abruptly after having passed the billboard. These effects were stronger the more words were displayed on the billboard.

Zalesinska (2018) conducted a study about the effects of luminance, size and location of light emitting static digital billboard on response times (the onset of braking) when drivers passed a static digital billboard at night and a sudden event (e.g. a pedestrian suddenly crossing the road) occurred. This was a simulator study. Luminance, size, and location of the billboard all had an effect on response time. The more light the digital billboard emitted, the larger the illuminated billboard was, and the closer the billboard was located near the Focus of Expansion (see Figure 4.4), the later the participants braked. There were also significant combined effects (interaction effects) of luminance and size and of luminance and location, but not of location and size. There also was no three way interaction effect of illumination, size, and location. Luminance had the largest impact on response time. The lighting conditions were: 0 cd/m^2 (Candela per square meter), 200 cd/m^2, 400 cd/m^2, and 800 cd/m^2. The difference in response time latency was the largest between 0 cd/m^2 (no luminance) and 200 cd/m^2. The response time increased with approximately 100 ms when the advertisement emitted 200 cd/m^2 relative to the condition in which the advertisement emitted no light.

4.6.2 Previous literature reviews

The present literature review about the effects of roadside advertisements on crash rate and driving behaviour is not the first literature review on this topic. The previous reviews are briefly summarized in this paragraph.

The literature review of Brijs et al. (2014) is in Dutch and is about static digital billboards and video billboards. The authors conclude that epidemiological studies based on crash rates near billboards do not yield sufficient evidence that these billboards increase crash risk. There are only a few epidemiological studies and these studies are based on too few crashes. The authors conclude that there is however sufficient evidence that these types of billboards do distract drivers. Static digital billboards and even more so video billboards negatively influence gaze behaviour and driving performance. Brijs et al. (2014) stress the negative effect of 'visual clutter' caused by billboards; when these billboards are located near complex road and traffic situations with lots of road signs, they can hinder scanning for relevant information. The authors also stress the danger of glare caused by too brightly illuminated billboards. However, they do not refer to studies that have explicitly investigated the negative effects of visual clutter and glare caused by static digital billboards and video billboards.

Decker et al. (2015) conducted a literature review of the effects billboards of any kind may have on visual behaviour. The authors conclude that there is sufficient evidence that when drivers look at billboards, 10-20% of glances are longer than 0.75 seconds. Video billboards and static digital billboards (at around the moment the advertisement switches) distract drivers more than traditional static billboards. Occasionally, fixations can be over 2 seconds at video billboards and static digital billboards, but the authors conclude that it is not possible to provide an accurate prevalence. Although video billboards and static digital billboards elicit longer fixations than traditional static billboards no evidence was found that dwell times differed between the digital billboards and the traditional static billboards. Furthermore, the authors did not find evidence that billboards in general affected glances at expected driving-relevant stimuli, or the proportion of time drivers spent glancing at the forward roadway. However, they did find evidence that especially the video billboards and static digital billboards negatively affected glances at unexpected driving-relevant stimuli such as a lead vehicle that suddenly brakes, and that vertically scanning decreased.

The report of Wachtel (2016) is not a literature review in the true sense of the word. It is mainly a compendium of recent studies on static digital billboards and video billboards. The author concludes that recent studies indicate that due to their salience static digital billboards and in particular video billboards attract more attention than traditional static billboards. These ‘Commercial Electronic Variable Message Signs (CEVMS)’ affect the glance behaviour and driving performance of young novice drivers more than that of older and more experienced drivers. The author also mentions that the most recent epidemiological studies tend to indicate (but not prove) that CEVMS increase crash risk. However, some of the recent epidemiological studies that showed no effect on crash rate are missing in this compendium.

Finally, Ziakopoulos et al. (2017) reviewed the literature about crash rate, glance behaviour, and driving performance that are associated with ‘outside factors’. These outside factors were billboards but also other objects or events and included even sun glare. Only four of the twelve included studies about outside factors were about billboards. The authors conclude that in general outside factors increase crash rate. However, in the only study about the effect of roadside advertisement on crash rate they included (Yannis et al., 2013) it was found that roadside advertisement did not increase crash rate. Although this study has sufficient statistical power the design is rather weak. It is a before-and-after study without a comparison site.

5 Findings structured within the SEEV-framework

According to the SEEV-framework presented in Chapter 3, distraction by roadside advertisements is caused by their *salience*, by the *effort* road users have to invest to 'read' the billboards, by the *expectations* of the road users, and by the *value* the content and appearance of the messages have for road users. In addition, drivers can be dazzled by the *luminance* of billboards. This chapter presents these five determinants and their factors with (in italic) what the literature review has revealed about these factors. It is important to note that many studies did show an effect of a certain factor but that the results were hardly ever precise enough to allow for concrete quantitative recommendations. For example, exposure time of an advertisement on a static digital billboard has an effect on gaze behaviour and driving behaviour. However, it is not possible to state that when exposure time increases with X seconds the change in behaviour Y will be Z percent.

5.1 Salience

Factors related to Salience are:

- The presence of moving images (videos) or animations
  When video billboards were included in the studies, these billboards had the most deteriorating effect on gaze behaviour and driving performance, especially for young drivers.

- Other movement such as rotating advertisements
  No studies included rotating objects (such as the three slowly rotating advertisements placed on a pillar in Figure 5.1).

Figure 5.1 *Example of three slowly rotating illuminated traditional static billboards that are placed on a pillar.*

Fast moving objects grab the attention but very slow rotating objects probably not so much. However, no studies were found regarding this topic.

- Lighting, colour and contrast with background
  This factor is not about glare that brightly illuminated billboards can cause but about their increased conspicuity because they stand out against the background. The effects of increased conspicuity are difficult to investigate in simulators but have been investigated in the field studies. No clear evidence was found that illuminated billboards affected gaze behaviour more when it was dark than during daylight. It is however important to note that only static digital billboards were included in these field studies and that they probably emitted no more light than was allowed by the regulations.

- Exposure time of an advertisement on a digital billboard
  Both in simulator studies and in field studies it was found that at the moment a switch of advertisements occurs, they attract the most visual attention. More drivers tend to look at these billboards at those moments and when they look, they look longer. The less drivers experience a switch of the advertisement when they approach, the less drivers will be distracted by static digital billboards. This implies that the longer the exposure time of an advertisement on a static digital billboard, the better this is for road safety.

- Transition from one advertisement to the other on static digital billboards
  No studies were found about the way an advertisement on a static digital billboard is replaced by another. These transitions can be quick without a brief period with a black screen between the two advertisements or slow with a black screen between the two advertisements. It is also possible that the old advertisement slowly fades out and the new advertisement slowly fades in. There is no consensus between experts. Some argue that transition should be slow and others argue that transition should be as fast as possible (e.g. Wallace, 2003a).

5.2 Effort

Factors related to Effort are:

- Position of the advertisement in relation to the forward view of the driver
  The studies clearly indicate that the closer the billboard is located near the default gaze direction of drivers (i.e. the forward road view), the more drivers will glance at the billboard. Billboards at street level attract more attention than when they are placed a couple of metres above the ground. The more drivers have to turn their head in order to 'read' the advertisement, the less often they will take the effort to look at it. However, when they do look for instance at billboards that are placed alongside the road, the longer their eyes will be away from the forward road view (Crundall et al., 2006).

- Size of advertisement
  Only one study was found in which the size of the billboard was an independent variable (Zalesinska, 2018). The larger the static digital billboard was in this study, the longer it took drivers to start to brake when an acute hazard suddenly materialized at the moment billboard was in sight.

- The visual clutter in the forward view of drivers (e.g. buildings, other billboards, and road signs that surrounds the advertisement)

In for instance urban areas or in industrial zones, the road environment may provide so much irrelevant visual information that it is difficult for the driver to select the information that is relevant for driving (Edquist, 2008). This is called 'visual clutter'. No studies were found in which the visual clutter that is caused by billboards was explicitly analysed. Experts argue that because of the fact that visual clutter may deteriorate driving performance, billboards and especially static digital billboards or video billboards should not be placed near road and traffic situations where drivers have to concentrate on the driving task and to take decisions such as near intersections (e.g. Wallace, 2003b). In most guidelines it is stated that because of the danger of visual clutter there should be a minimum distance between one static digital billboard and the other (see for an overview: OMA 2014). Although it is better to avoid visual clutter it appears from the evidence that drivers are capable of some kind of self-regulation. When the road and traffic situation is complex drivers tend to concentrate more on the driving task and tend to look less often at billboards (Young et al., 2017).

- Font size of the letters on billboards
  No studies were found that examined font size of the letters on billboards. The study of Marciano and Setter (2017) indicates that billboards with only a few words in large font size deteriorated a tracking task that resembles steering the least.

- The amount of text on a billboard
  The more text displayed on a billboard the more lateral control deteriorates when drivers try to read the billboard (Schieber et al., 2014). However, it could be in real world driving that drivers decide not to read a billboard when it contains a lot of text.

- The composition of pictures and text on a billboard
  The so called loaded advertisements with various text blocks and pictures deteriorated a tracking task the most (Marciano & Setter, 2017).

- The traffic density at the spot of the advertisement
  In the simulator study of Marciano and Yeshurun (2012) it was found that when the traffic density was low, participants more often looked at billboards and that the dwell times were also longer than when the traffic density was high. This indicates that there is some kind of self-regulation. Despite this self-regulation, drivers start to brake later when a lead vehicle suddenly brakes when they approach a static digital billboard compared with when there are no billboards (Milloy & Caird, 2011).

- The complexity of the traffic situation at the spot of the billboard
  There are indications that billboards affect decision making in complex road situations. In the simulator study of Edquist et al. (2011) participants more often did not change lanes when a static billboard was present opposite the road sign that indicated that drivers had to change lanes, compared with when there was no billboard.

5.3 Expectations

Factors related to Expectations are:

- Do the advertisements look like road signs?
  No studies were found about this subject.

- Are the advertisements placed at spots where drivers search for relevant information for the safe execution of the driving task?
  In the field study of Smiley et al. (2005) the static digital billboards were placed in an urban area near intersections with road signs and traffic lights. Drivers more often did not look at road signs after the billboards were placed, compared with before they were placed.

- Do the advertisements (partly) block the view of information that is relevant for the safe execution of the driving task?
  No studies were found about this subject.

- Does a billboard refer to information that will be on a next billboard along the road (e.g.: “See our next billboard along this road what we can offer you.”)?
  No studies we found about this subject.

5.4 Value

Factors related to Value are:

- Content of message, pictures and or texts that may evoke emotions
  There are indeed indications that emotion-arousing pictures and words have an effect on driving performance. These effects are small and sometimes they can also improve driving performance.
- Content related to current goals of the driver (for example food, drink)
  No studies could be found in which for instance hungry participants and participants that are not hungry search for billboards that inform drivers about restaurants in the neighbourhood.
- Text that encourage drivers to engage in distracting activities (e.g. using their mobile phone).
  No studies were found about advertisements on billboards that encouraged drivers to carry out distracting activities such as texting.

5.5 Luminance

Factors related to Luminance that are not related to salience, are:

- Does the illuminated billboard/object cause glare?
  Whether illuminated billboards cause glare is difficult to investigate in a simulator. One simulator study was found on this topic (Zalesinska, 2018). In this study was found that while driving in the dark, a luminance of 200 cd/m^2 already had some deteriorating effects on driving performance. In all the field studies that were found in which participants drove in the dark and passed static digital billboards or video billboards, the problem of glare is never mentioned. It could be that glare is not mentioned because the existing illuminated billboards in these studies met the local requirements about illumination. In most of these regulations, the maximum amount of light a certain surface is allowed is related to the background light. There is more background light during hours of darkness on urban roads than on rural roads. It could also be that glare is never mentioned because no older drivers participated in these field studies.

- Does the brightness of the illuminated billboard make unilluminated road signs almost invisible?
  No field studies were found in which participants were not able to read the road signs in the dark because a billboard next to the road sign emitted too much light.

6 Overall conclusions

Five studies were found about the association between crashes and roadside advertisements. The results are inconclusive. In one study an increase in the number of crashes was found near billboards and in the four other studies not. However, it is very difficult to assess the effect of billboards on crash risk. One issue is the lack of statistical power. Because crashes are rare events and the stretches of road in which a billboard could contribute to a crash are short, the included number of crashes was mostly small. One of the five studies, a study in which no effect on crash risk was found, indeed seems to lack statistical power but in the four other studies power seems to be sufficient. Another issue is the research design. Three of the five studies were before-and-after-studies (comparing the crash rate before the placement of billboards and the crash rate after the placement of billboards) and in two studies a comparison site was also included. A before-and-after-study with a comparison site is a stronger research design than a before-and-after-study without such a group. There were two studies with sufficient statistical power and a comparison site. In one of them an increase of crashes near billboards was found, but not in the other.

Because of this, studies that focus on SPIs such as looking behaviour and driving behaviour are the best available to make an assessment of the safety of billboards.

Approximately half of drivers do not look at billboards when they pass them. However, those drivers that do, look more often and longer at static digital billboards (in particular at moments that the advertisement switches) and even more so at video billboards than at traditional static billboards. They more often look at billboards at street level than at raised level, but when they look at billboards at raised level they tend to look longer. Young novice drivers are inclined to look at static digital billboards and video billboards the most. Drivers rarely look longer than two seconds at a billboard. However, sometimes they do, especially when it is a static digital billboard or a video billboard. This is worrying as long glances at objects outside the vehicle increase the crash risk substantially (Dingus et al., 2016).

There is quite strong evidence that lane keeping deteriorates when drivers look at billboards. Billboards do not seem to have a strong impact on speed. In some studies it was found that headways get shorter in particular when drivers pass static digital billboards and video billboards. This is dangerous because response latencies are longer when drivers look at billboards. They for instance brake later in time when they look at a billboard and a lead vehicle suddenly brakes. Drivers also more often overlook road signs and tend to forget to signal when they change lanes near billboards. The content of what is displayed on billboards does not seem to influence driving behaviour very much. What is displayed on the advertisements (arousing pictures and texts) influences decision making and driving performance only slightly. However, more research is needed to assess the effect of emotion-laden pictures and text on driving behaviour.

The less demanding the driving task, the more drivers let their eyes wander to irrelevant objects. It seems that most drivers are capable of regulating adequately the attentional resources the driving task requires (Young et al., 2017). However, in traffic the task demands can suddenly increase and these events (e.g. a lead vehicle that suddenly brakes) are not always properly anticipated. In those circumstances looking at billboards can have detrimental effects.

In most field studies no difference was found in gaze behaviour at illuminated billboards during day and night. This does not mean that LED billboards (light-emitting diode billboards) such as most static digital billboards and video billboards do not have an impact on driving behaviour. Most jurisdictions regulate the amount of light billboards are allowed to emit. The illuminated billboards drivers passed at night in these field studies most probably were in compliance with these regulations. Illuminated billboards definitely can cause glare. In her simulator study, Zalesinska (2018) found that the more light a billboard emitted the longer the response latencies were when an acute threatening situation such as a pedestrian that suddenly crossed the road, occurred.

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