Do LED-advertising signs affect driver attention?

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Abstract: With the purpose of investigating how LED-advertising signs (LED) affect drivers' attention compared to static signs and other kinds of distractors along roads, a new Danish empirical on-road study has been carried out by using an instrumented car equipped with a camera system to monitor eye movements. Speed behaviour was recorded by use of GPS and additionally a laser scanner was used for measurement of distances to vehicles ahead. In total, 16 different test drivers drove a test route making 228 drive pasts of different LED-advertising signs. The test drivers were not informed about the main purpose prior to the test drive. Eye track data verified whether the driver was glancing at the LED-advertising signs (the number of glances, glance duration and glance angles). Different algorithms for detection of driver distraction were used. Critical situations were identified and analysed in detail to uncover the identity of distractors. Driving in daylight were compared with driving in darkness.

Results showed that drivers' visual attention was diverted by LED-advertising signs. In more than every 10th drive past *visual distraction occurred*, e.g. cumulative glances of more than 2 sec. within a 6 sec. period, when the driver looked at the LED-advertising. In 4 % of the drive pasts visual distraction occurred together with a "safety buffer" less than 0 sec. The safety buffer reflects the time available to respond to a sudden critical event requiring immediate action in order to avoid an accident.

1. Introduction

The number of advertisements along Nordic roads is rapidly increasing. Moreover, the signs are becoming larger and more sophisticated. LED-technology has led to an acceleration of this development in recent years. The new LED-advertising signs are capable of displaying both large-format colour changing advertisements and moving images. This technology is used deliberately to divert and maintain the attention of the drivers.

On this background, The Nordic Committee for Visual Conditions in Road traffic (NMF) in 2015 decided to launch a research project with the aim of investigating whether and to what degree LED-advertising signs along roadways affect the visual behaviour of drivers. The research work has been carried out by a research team from Trafitec in Denmark [1].

The purpose of the study was to perform empirical studies that can provide the basis for answering the following questions:

1. To what extent do LED-advertising signs along roads divert drivers' visual attention?
2. Is drivers' visual attention to LED-advertising signs diverted and maintained to such an extent that it affects road safety?

3. Compared to other types of distractors, to what extent is the visual attention diverted by LED-advertising signs?
4. Does drivers' visual attention to LED-advertising signs differ during daylight and darkness?

In addition, it is researched if the complexity of the surroundings to the LED signs, the size and the right/left placement of the LED signs affect drivers' visual attention.

Initially, a comprehensive literature study has been carried out [1] and a short summary based on selected references is provided in section 2.

2. Summary of literature study

Several foreign studies, including a study from Brunel University (Young and Mahfoun 2009) [2], have demonstrated that roadside advertising signs have a clear impact on the drivers' lane position control. The results suggest that roadside advertising may increase the mental stress and divert the road user's attention away from the traffic.

The effect of roadside advertising may be more pronounced in monotonous traffic situations where the mental stress is low compared to urban area driving where the mental stress is already relatively high (Chattington et al 2009) [3].

Studies have shown how increased visual complexity in the traffic environment – number of road signs, advertising signs and other information – results in the driver needing more time to search for road direction information (Akagi et al 1996) [4]. This accounts particularly for elderly drivers who generally have less capacity to ignore irrelevant information in the traffic (Helmers et al 2004) [5].

In a Finnish field study conducted by J. Luoma in 1988 (Fabry et al 2001) [6], it was demonstrated that drivers are using significantly more time to perceive the message of an advertisement (2.3 sec.) compared to the time they spend on perceiving the message on a speed sign (0.5 sec.).

Canadian studies of video advertisements (Smiley 2005) [7] resulted in the following conclusions:

- Video advertisements diverted the drivers' attention and in several cases this possessed a danger to the road safety because the time gap to vehicles ahead was very short (1 sec. or less) at relatively long eye glances (glance duration exceeding 1.5 sec.) and with relatively wide angles away from the roadway ahead.
- When drivers were looking at the video advertisements, an entire 38% of the time gaps to the vehicle ahead were less than 1 sec., and a quarter of the glances went away from the roadway at an angle of 20 degrees or more from the road ahead.

- Drivers tend to look more at digital video advertisements than at conventional static advertising signs. They glance several times and the glance duration is longer.
- On roads leading to intersections with visible video advertising, a significantly higher number of conflicts in the form of sudden braking was reported. And a slower start of vehicle was reported at traffic lights changing to green.

In a British study by the Transport Research Laboratory (Chattington et al 2009) [3], a driving simulator test compared the impact on driving behaviour of video advertising signs and static advertising signs respectively. The main results showed that:

- Drivers glance longer and more frequently at video advertising signs compared to static signs.
- The advertising signs affect the drivers' control of lane positioning. The variation in lane positioning is larger at sites with video advertising signs.
- There are more incidents of sudden braking linked to video advertising signs.
- The speed is decreased when passing video advertising signs.
- Generally, video advertising signs have a bigger impact on road user behaviour compared to static advertising signs.

A Swedish study (Dukic, T. et al 2011) [8]., with on-road test drives on a highway passing 4 electronic advertising signs showed that drivers' visual attention was diverted by the advertisements. Both in daylight and in darkness, examples of glance durations of up to 6-7 seconds when passing the advertising signs were observed.

In a Danish study (Herrstedt, Greibe and Andersson 2013) [9], empirical studies of the influence of static advertising signs along rural roads were carried out. The study is based on test drivers' on-road test drives by use of an instrumented car (Naturalistic driving). 32 test drivers completed 109 drive pasts of 16 large static advertising signs. A total of 223 glances at the signs were registered. The results of the analysis showed as follows:

- In 69% of all drive pasts the driver glanced at the advertisement at least once and in almost half of the drive pasts the driver glanced twice or more at the same advertising sign.
- Most glances at the advertising signs had a short duration. However, 44% of the glances had a duration of 0.5 sec. or more. 18% of the glances at the signs had a duration of 1 sec. or more.
- In 22% of the drive pasts, the total duration of one or more consecutive glances at the advertisement was 2.0 sec. or more, and for 10% of the drive pasts the duration was 3.0 sec. or more.

- In almost 25% of such cases where the driver glances at the advertising sign, this happens while the safety buffer to drivers ahead is less than 2 sec. - and in 20% of the cases less than 1.5 sec.
- For more than 20% of the registered glances at advertising signs, a combination of glance angle and glance duration outside the normal visual behaviour when driving on rural roads was found.
- In more than every sixth drive past the driver was glancing at the advertising sign to a point where it was considered “visual distraction”.

On this basis, the study concluded that the large, static advertising signs along rural roads divert and maintain the visual attention of drivers to such a degree that it affects road safety.

In a new field study based on "naturalistic driving" (Belyusar, Mehler, Reimer, Coughlin, 2016) [10] 123 test drivers were exposed to two large LED-advertising signs on the RT 93 highway north of Boston in the United States. The posted speed limit on the segment of roadway was 65 mph. The car was equipped with cameras enabling monitoring of the driver’s eye movements. Results showed a significant shift in the number and duration of glances away from the roadway and the traffic due to the glancing at the LED-advertising signs. This visual behaviour was particularly evident at the point in time where the LED-advertising signs were changing. The study concluded that because such rapidly changing or moving stimuli is difficult for drivers to ignore, the increased number of LED-advertising signs near the roadways in the United States is a traffic safety concern.

2.1 Conclusion on the literature study

Roadside advertising signs are very diverse, as are people. Size, movement and light however are powerful artefacts affecting most of us, more or less. The many studies of driver impact from advertising signs show a big variation of results. Some studies show only small effects, but overall, results from a large number of research projects show that advertising - and especially the more aggressive type - may divert drivers’ attention and affect driver behaviour to such an extent that it has a detrimental effect on the road safety.

3. Method used in the current empirical study on LED-advertising signs

The current study is conducted by test drivers in an instrumented car driving on routes with various LED-advertising signs (naturalistic driving study).

3.1 Test drivers

All test drivers were required to possess a valid Danish driving license, to be a regular driver, be at least 25 years of age and not to wear glasses when driving. The latter was necessary to secure high data quality from the eye track system.

The test drivers were not informed about the main purpose of the drive prior to the test drive. Instructions given to all test drivers on beforehand were the same. The test route was presented on a map and drivers were informed about length of the route and duration of the drive (approximately 1 hour). They were asked to respect the speed limits and drive as usual without unnecessary conversation with the observer sitting in the backseat. During the drive, the observer instructed the test driver when to turn right or left.

Test drivers were recruited amongst members of Trafitec's test panel, which includes drivers of different ages and sex, education and place of residence. Furthermore, recruitment took place by use of posters at e.g. work places and student hostels. The test drivers were living in the region of each of the two test routes, and were all familiar with parts of the route.

3.2 The instrumented car

The instrumented car includes a SMART EYE 3-camera system for monitoring of eye movements, a scene camera for video detection of the traffic situation ahead, GPS for registration of speed and a laser scanner (Ibeo Lux) placed in the car front for measurement of distances to other road users ahead. An extra video camera was installed inside the car with the purpose of observing the driver's head movements.

The collected data verifies whether the driver is looking at the LED-advertising signs and the number of glances. Glance duration and glance angles are measured as well. These measurements are related to present driving speed and distances to other road users and thereby critical situations are detected.

3.3 Safety buffer

In order to answer question 2), a "safety buffer" is calculated. The safety buffer reflects the time available for the driver to respond to a sudden critical event requiring immediate action in order to avoid an accident.

The time gap to the vehicle ahead is calculated by measuring the distance to the vehicle ahead and the driving speed. In situations where the time gap to the vehicle ahead is larger than 3 sec., the test driver is defined as "free running", meaning without vehicles ahead.

In situations where the test driver is looking at an advertising sign while a vehicle is positioned within a time gap of 3 sec. ahead, a "safety buffer" is calculated:

$$T\,(\text{sec.}) = l\,(\text{sec.}) - t\,(\text{sec.})$$

Where

T = Safety buffer (sec.)

l = Time gap to driver ahead (sec.)

t = Advertising glance duration (sec.)

If the distance from test driver to vehicle ahead e.g. is 1.09 sec., and the glance duration at the advertising sign is 0.75 sec., a safety buffer of T = 1.09 sec. - 0.75 sec. = 0.34 sec. can be calculated (Figure 1). In other words, the safety buffer decreases when looking away from the roadway ahead. The safety buffer is a measure of the maximum time in which the driver has to perceive, interpret and respond to a sudden event registered by the driver after re-directing the eye glance away from the LED and back to the road ahead.

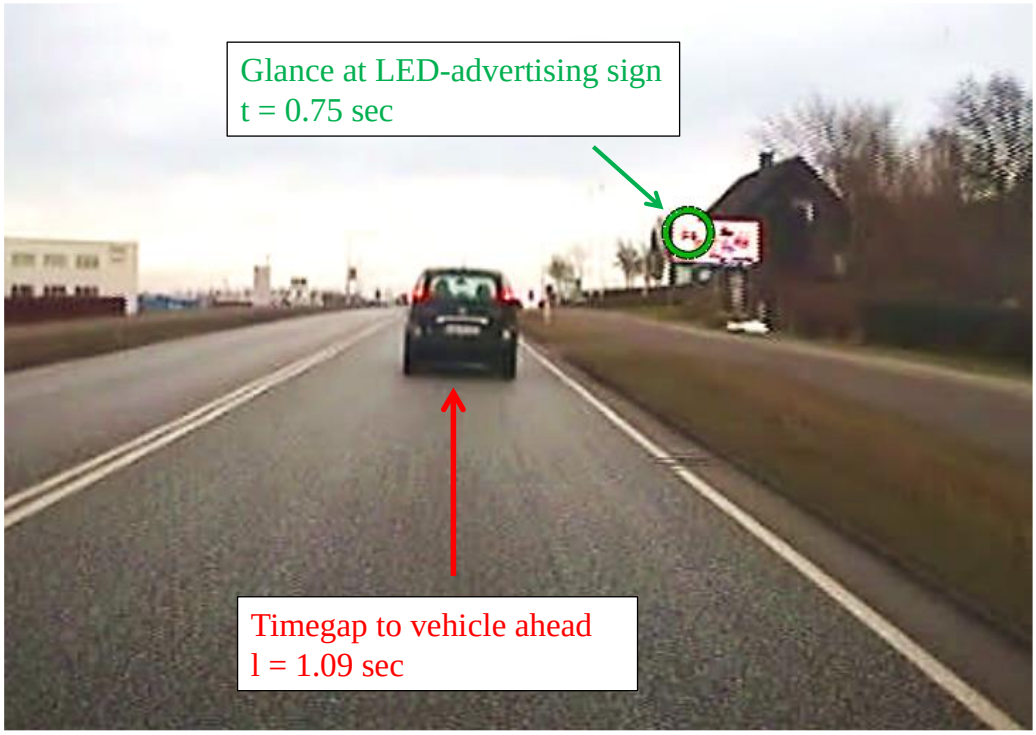

Figure 1. *Example of LED-advertising glancing (glance duration= 0.75 sec.) in combination with a vehicle ahead (time gap 1.09 sec.)*

3.4 Visual distraction

The second key parameter underlying the response to question 2) is the number of detected situations with visual distraction.

Visual distraction can be defined as: Diversion of drivers' visual attention away from the roadway and traffic towards a competing activity/object irrelevant for the driving task [13], [14].

Different algorithms for detection of driver distraction have been introduced in international research, and different choices of algorithms have been used to operationalise detection and estimation of driver distraction (Kircher and Ahlström, 2013) [11].

In a study carried out by Klauer et al (2006) [12] video recordings were analysed to determine when the driver looked away from the roadway. Visual distraction was estimated by the cumulative glance duration away from the roadway in a 6-second sliding window, and the driver was considered distracted, when the distraction estimate exceeded 2 seconds.

This threshold gave results that were expressively associated with crash/near crash involvement: When a driver is looking away from the roadway ahead at driving-irrelevant stimuli for a total period of at least 2 seconds within a 6-second continuous period, the risk of being involved in an accident or near-crash situation almost doubles. This algorithm for detection of distraction has been used in this study.

3.5 Background data for the analysis

A test drive is a completed drive through a route, along which various LED-advertising signs are passed. For each of the two routes, 6 test drives were performed in daylight and 4 in the dark. Hence, data for a total of 20 test drives on both routes has been collected, including 12 test drives during daylight and 8 during dark. The test drives were carried out by 16 different test drivers, by which 4 of the test drivers performed a test drive in both daylight and darkness.

In relation to two of the 20 test drives, the eye-tracking system failed (with lack of data) and for a few drive pasts the LED-advertising was not active. All together this meant, that 22 of 250 completed LED drive pasts had to be excluded from the analysis. This provided data for a total of 228 LED drive pasts, of which 145 were carried out in daylight and 83 in darkness, see table 1.

All test drives were conducted outside peak hour e.g. in daylight between 10 a.m. and 3 p.m. and in darkness between 6 p.m. and 9 p.m.

Table 1. Number of test drives and drive pasts of LED-advertising signs in daylight and darkness

Test route	No. of LED-advertising signs	Daylight		Darkness		Total	
		Test drives	LED drive pasts	Test drives	LED drive pasts	Test drives	LED drive pasts
Hundige	6	6	36	4	20	10	56
Aarhus	19	6	109	4	63	10	172
Total	25	12	145	8	83	20	228

Figure 2. *Examples of the LED-advertising signs included in the study*

4. Results

The results of the study are presented below along with a number of partial conclusions to answer the four primary questions, which were initially listed in the introduction.

4.1 To what extent do LED-advertising signs along roads divert drivers' visual attention?

How often does the driver glance at the LED-advertising sign?

The average number of LED glances per drive past is 1.7. Not surprisingly, there is some variation in the results from individual test drivers and LED advertisements depending on the specific situation. The number of LED glances per drive past ranges from 0 and up to 14 glances. In 61% of all drive pasts the test driver has at least one glance at the LED-advertising sign. In daylight, the percentage is 63% and in darkness 58%. Table 2 shows in more detail the number of drive pasts (N=228) according to the number of LED glances per drive pasts.

Table 2. Number of observed drive pasts by the number of LED glances per drive past.

Number of LED glances per drive past	Daylight		Darkness		Total	
	No.	%	No.	%	No.	%
0	54	37%	35	42%	89	39%
≥ 1	91	63%	48	58%	139	61%
≥ 2	61	42%	32	39%	93	41%
≥ 3	39	27%	22	27%	61	27%
≥ 4	26	18%	13	16%	39	17%
≥ 5	14	10%	10	12%	24	11%

In 41% of all drive pasts the driver glances twice or more at the LED-advertising sign. In daylight, the percentage is 42% and in darkness 39%. Drive pasts with two or more LED glances are observed among 15 different test drivers and 18 different LED signs. In 27% of all drive pasts the driver glances 3 times or more at the LED-advertising sign and for 11% of all drive pasts, the driver glances at least 5 times at the LED-advertising sign.

For how long does the driver glance at the LED-advertising sign?

In total 397 LED glances, has been observed and the average LED glance duration is 0.91 sec.

11% of all glances at LED-advertising signs has a duration of more than 1 sec. The longest measured glance at an LED-advertising sign has a duration of more than 7 sec., and in several cases a 3-4 sec. single glance duration was measured.

Table 3 shows the number of LED glances (N=397) by the duration in daylight and darkness.

Table 3. Duration of LED glances in daylight and darkness.

LED glance duration (sec.)	Daylight		Darkness		Total	
	No.	%	No.	%	No.	%
0.00-0.50 sec.	166	65%	106	72%	272	68%
0.51-1.00 sec.	51	20%	33	23%	84	21%
1.01-1.50 sec.	19	8%	4	3%	23	6%
1.51-2.00 sec.	3	1%	0	0%	3	1%
2.01-2.50 sec.	4	2%	1	1%	5	1%
2.51-3.00 sec.	4	2%	0	0%	4	1%
> 3.00 sec.	5	2%	1	1%	6	2%
Total	252	100%	145	100%	397	100%

In 15% of the drive pasts the driver glances (in one or more consecutive glances) for 2 sec. or more, and in 10% of all drive pasts the driver glances at the LED-advertising sign for a total of 3 sec. or more.

The LED-advertising sign may not always be visible during the entire drive past due to heavy vehicles blocking the drivers view. Only time periods where LED signs were visible during the drive past have been included in the analysis.

On average, drivers glance at the LED-advertising sign is just above 4% of the time where LED is visible. However, this varies between 1-12%. Thus, there is a big difference in terms of how much the individual advertising signs are being glanced at.

4.2 Is drivers' visual attention to LED-advertising signs diverted and maintained to such an extent that it affects road safety?

The occurrence of visual distraction

When driver's total glance duration at the LED-advertisements reaches 2 seconds or more within a consecutive period of 6 seconds, visual distraction occurs. In situations with visual distraction the risk of being involved in an accident or near-crash situation almost doubles.

A total of 26 occurrences of visual distraction have been detected. This corresponds to 11% of all drive pasts.

Visual distraction occurs more often when the LED-advertising sign is placed in an environment with a low degree of visual complexity.

Safety distance to road users ahead

In situations where the driver has glanced at the LED-advertising sign whilst another vehicle ahead within a 3-second time gap, a safety buffer has been calculated. This is the case for 142 out of 397 LED glances. The safety buffer decreases when the driver is looking away from the roadway ahead to glance at the LED-advertising sign. The safety buffer is a measure of the maximum time in which the road user has to avert a sudden critical event requiring immediate action to avoid an accident.

In 59 LED glances (equals 15% of the total), a safety buffer ≤ 1 second has been observed. The 59 LED glances are found among 13 different test drivers and 15 different LED-signs. Thus, a low safety buffer is found among a wide range of test drivers and LED signs.

The results also show, that in 10 LED glances (equals 3% of the total), the safety buffer is negative (<0 second). Situations with very little or negative safety buffer are associated with a significantly increased risk of accidents. The 10 LED glances with a negative safety buffer are represented by 4 different test drivers and 8 different LED signs.

Traffic safety is affected

Situations of visual distraction and situations of very little or negative safety buffer are both independently associated with increased risk. As a consequence, situations where both conditions occur simultaneously are very critical due to the significantly increased risk of traffic accidents.

In 5% of all drive pasts (11 out of 228) visual distraction occurs together with a low safety buffer of ≤1 second and in 4% of all drive pasts visual distraction occurs together with a *negative* safety buffer.

4.3 Compared to other types of distractors, to what extent is the visual attention diverted by LED-advertising signs?

Two sub-studies a) and b) have been carried out to elucidate this question.

a) What is the driver looking at in situations with a "critical glance" during daylight driving?

A screening for "critical glances" has been conducted for the entire daylight test drives (both test routes). A "critical glance" has been defined as a fixation with a duration of more than 1 second and a glance angle exceeding 10 degrees. For each of these "critical glances" it was identified what the driver was looking at.

Glances at LED-advertising signs, other advertisements, spectacular objects etc. is referred to as *non-driving-related* glances. Glances at road signs/traffic lights, road/road users, mirrors/speedometer is referred to as *driving-related* glances.

The results showed that 1/3 of all "critical glances" were *non-driving-related*.

LED-advertising signs and other advertisements together account for a large proportion (69%) of the non-driving-related "critical glances". 17% is diverted to LED-advertising signs and 52% to other advertisements. In this context, it should be noted that the number of "other advertisements" is estimated to be more than 10 times as large as the number of LED-advertising signs on the current test routes.

The average glance duration of all "critical glances" at LED is 1.63 sec. The average glance duration of "critical glances" at LED-advertising is longer compared with "critical glances" at other types of objects. The average glance duration for *road signs* were 1.12 sec., for *road &traffic* 1.39 sec, for *mirrors* 1.12-1.31 sec., *instrument board* 1.17 sec. and *other kinds of advertising* 1.56 sec.

b) What are drivers looking at when passing LED-advertising signs?

When passing LED-advertising signs in daylight (including all *advertising road sections*), an identification of all objects being glanced at (during time when the LED-advertisement is visible to the test driver) was made.

Results show, that the majority of the drivers' visual attention to objects outside the car is diverted to driving-related objects such as *the road and other road users* as well as *road signs and traffic lights* (almost 86% of the time where the LED-advertisement was visible to the test driver).

The remainder visual attention of the drivers (14%) is diverted to other *non-driving-related* objects of which LED-advertisements account for about half. Overall, LED-advertising signs and other advertisements make up approximately 10% of the drivers' visual attention in terms of glance duration, while road signs and traffic lights account for 7% of the glance duration.

4.4 Does drivers' visual attention to LED-advertising signs differ during daylight and darkness?

- There is no significant difference between daylight and darkness in relation to how often a driver glances at an LED-advertising sign when passing this.
- The LED-glance duration is longer in daylight, where 15% of the glances at LED-advertising signs exceeds a duration of 1 sec. During darkness, this is only 5%.
- The longest measured glance at an LED-advertising sign in daylight has a duration of more than 7 sec. while in darkness the duration is 3.9 sec.
- Visual distractions occur equally frequent in daylight and darkness.
- During daylight, 18 occurrences of visual distractions were registered representing 12% of the drive pasts. In darkness, visual distractions occurred in 8 cases representing 10% of the drive pasts.

Statistical tests show that neither the number of glances nor the total glance duration differs significantly when passing LED advertising, respectively in daylight and darkness (Mann-Whitney, p=0.602; p=0.476).

Nothing indicates that LED-advertising signs divert more attention in the dark than in daylight. A possible explanation may be, that all road sections included in the analysis are equipped with street lighting, meaning that the LED-advertising signs do not appear in a completely dark environment at night.

4.5 The visual complexity of the surroundings to LED-advertising signs affects the visual attention

Some LED-advertising signs have an almost solitary location along the roadway, while others are located in environments with many other objects, e.g. other advertisements, traffic lights, road signs etc. The more complex the surrounding environment, the more distractors to compete for the drivers' visual attention.

In order to analyse this issue, the degree of visual complexity of the surrounding environment in which the individual LED-advertising signs are placed, has been evaluated by an expert panel by use of a relative scale: low / medium / high.

The results of the subsequent analysis suggest that LED-advertising signs placed in environments with a low degree of visual complexity divert driver attention more compared to LED-advertising signs in environments of a high visual complexity.

Both total glance duration and visual distraction frequency is higher for LED-advertising signs in environments with a low visual complexity. No significant difference has been found between the total glance duration when passing LED-signs in low respectively high visual complexity surroundings (Mann-Whitney, p=0.400).

4.6 Some LED-advertising signs draw more attention than others

Results suggest that drivers spend significant more time glancing at large LED-advertising signs compared to small and medium-sized ones (Mann-Whitney, p=0.00017).

Glances on LED-advertising signs located in the right side of the road or in central island of the carriageway are significant more frequent than glances at LED-advertising signs in the left side of the road (Mann-Whitney, p=0.0316).

All things being equal, LED advertising signs placed in such way that they appear centrally in the visual field of the drivers will draw more attention.

5. Conclusions and discussion

The results of this empirical study of LED-advertising signs shows, that the drivers' visual attention is being diverted by LED-advertising signs. Thus, in 4 out of 10 drive pasts the driver glances twice or more at the LED-advertising sign, and in every 10^{th} drive past the driver glances 5 times or more at the advertisement. Overall, in 10% of the drive pasts the driver glances at the LED-advertising sign in one or more consecutive glances, for 3 sec. or more.

Situations of visual distraction and situations of very little or negative safety buffer are both independently associated with increased risk. Results show that, in 11% of all drive pasts, visual distraction occurs as a result of the driver glancing at the LED-advertising sign. In 15% of all drive pasts, the driver glances at the LED-advertising sign even if the safety buffer is low (< 1 sec.). In 4% of the drive pasts visual distraction occurs together with a negative safety buffer.

Most of the time drivers glance at driving-related objects. Though, LED-advertising signs divert a significant part of the drivers' non-driving-related attention. Results show that the average glance duration of "critical glances" at LED signs is longer compared to "critical glances" at other types of objects, including driving related objects.

The total glance time at LED-advertising signs account for approximately 7% of the time the LED is being visible. This corresponds to the proportion of time looking at road signs/traffic lights. LED-advertising signs represent approximately 50% of the glance time among non-driving-related glances.

Nothing indicates that LED-advertising signs divert more attention in the dark than in daylight. The test drives in daylight might of course be conducted under slightly different traffic conditions than the test drives in daylight. Further, all road sections included in the analysis are equipped with street lighting, meaning that the LED-advertising signs do not appear in a completely dark environment at night. These factors may influence the driver attention.

LED-advertising signs placed in environments with a low degree of visual complexity seems to divert driver attention more compared to LED signs in environments of a high visual complexity, but no significant difference has been found. If driver attention is diverted less by LED signs in high complexity surroundings it will not necessarily lead to the conclusion that drivers are engaging in a form of self-regulation. The LED-advertising is only one among a number of distractors on the studied high complexity locations. It is the impact from the LED signs we have focused, and despite a number of different competing distractors diverting driver's attention, we still detect *visual distraction* from the LED signs indicating that LED signs are very strong distractors.

Drivers spend significant more time glancing at large LED-advertising signs compared to small and medium-sized ones. Also, glances on LED-advertising signs located in the right side of the road or the central island are significant more frequent than glances at LED signs in the left side of the road. All things being equal, advertisements placed in such way that they appear centrally in the visual field of the drivers will draw more attention.

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