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Traffic management: assessing various countermeasures to improve detection failure of changes in speed limit signals

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Abstract

Under certain circumstances, drivers fail to notice changes in electronic speed limits. A video-based study was performed to reveal which countermeasures would improve drivers' ability to detect changes in electronic speed limits. Countermeasures included leaving electronic signs blank prior to a speed limit change and adding motion signals by means of flashing amber lights or a wave. A video representing a motorway was shown repeatedly to 255 participants. They were instructed to press the space bar when detecting a change. The video was viewed 13 times before the speed limit changed. Results showed that leaving signs blank prior to the change instead of displaying speed limits continuously did not alter change detection, whereas flashers and waves eroded detection of the changed speed limit. This suggests that using flashers and waves to attract attention to electronic signs in fact decreases people's ability to process the information contained in the signs.

Keywords: change blindness, variable speed limit, flasher

1. Introduction

As part of dynamic traffic management, variable speed limits have been introduced on motorways around the world. By adjusting these speed limits to fit the situation on the road, road authorities can improve both traffic safety as well as traffic circulation (Nissan, 2010; Van Nes et al., 2010). However, Nissan's simulation studies (2010) point out that the effectiveness of the system depends highly on speed

limit compliance. To achieve speed limit compliance, speed limits must be perceived, comprehended, accepted and retained (McGuire, 1968). The design of standard speed limits, contrary to other types of roads, cover most of these aspects; they have proven to be relatively well observed, to be considered meaningful, and to be relatively well recollected by drivers (Al-Gadhi et al., 1994; Harms & Brookhuis, 2016; Hoogendoorn et al., 2012; Johansson & Backlund, 1970; Johansson & Rumar, 1966; Lajunen et al., 1996; Luoma, 1991; Rämä, 2001). However, variable speed limits differ from standard speed limits considerably in the sense that variable speed limits *change*.

A large body of research has shown that under various circumstances humans fail to readily detect changes in the environment around them that are clearly visible (see Rensink, 2002, and Simons and Levin, 1997, for reviews). Even changes that are expected can easily be missed (Simons & Mitroff, 2001). This phenomenon – known as change blindness – has been repeatedly proven to impact human behaviour in many daily life activities, including participating in traffic. Change blindness generally occurs when transient motion signals that normally accompany a change are lacking (Zheng & McConkie, 2010). When electronic speed limits change because the limit increases or decreases, the change itself will lack motion signals for most drivers. This is because these speed limits are displayed on subsequent overhead gantries, so for most drivers the change will occur while they are driving from one gantry to the next. This makes it difficult to detect the change. A driving simulator study by Harms and Brookhuis (2016) pointed out that drivers indeed have difficulties with noticing changes in variable speed limits. Participants, unaware of the fact that they participated in a change blindness study, drove the same route twenty times to familiarise them with the route and the road equipped with overhead electronic speed limits. During the 19th drive, the speed limit changed from 80 km/h to 100 km/h. Of all drivers, 58.3% failed to notice this change even after repeated exposure to the new speed limit. Failing to perceive that a speed limit has changed yields an incorrect outcome in the first step of McGuire's (1968) information-processing steps to obtain compliance.

The perception of *changes* in electronic speed limits is an important prerequisite for speed limit compliance on roads equipped with variable speed limits. The current study is a follow-up to Harms and Brookhuis (2016). The objective of the current study is to improve drivers' ability to detect changes in electronic speed limits. To this end, countermeasures will be assessed in order to improve the effectiveness of variable speed limits as a traffic management measure. Additionally, this study aims to answer the question whether reintroducing motion signals – such as the commonly used flashers on electronic road signs – are in fact capable of capturing attention and redirecting it to the information contained in the signs.

2. Theoretical framework

Some studies have shown that many drivers have difficulties with detecting changes while driving, even when the changes are traffic related (e.g. Charlton & Starkey, 2013; Galpin et al., 2009; Lee et al., 2007; Velichkovsky et al., 2002). Failing to detect approaching 'hazards', such as pedestrians, motorcyclists and cars crossing the road, may result in collisions and near-crashes (Uchida et al., 2011; White & Caird, 2010). Failing to perceive changes in road signs results in incorrect interpretations of the information provided on which drivers base their driving behaviour (McGuire, 1968). This may lead to drivers speeding involuntarily and unknowingly (Harms & Brookhuis, 2016); to drivers failing to realise that the priority at a familiar intersection they are about to cross has changed (Martens & Fox, 2007); and eventually to fatal accidents, as shown by Muller and Verweij (1991). They investigated a fatal collision between a tram and a car at a signalised intersection. Whereas the tram driver stated he had perceived his sign giving him right of way, analysis of the traffic control system revealed that in fact this was not

the case. Although the sign usually gave the tram driver right of way, this time it signalled to yield; a change the tram driver had failed to notice.

Research on change blindness has shown that the lack of motion signals is a large contributor in the origin of change blindness (Galpin et al., 2009; Grimes, 1996; O'Regan et al., 2000; Rensink, 2002; Rensink et al., 1997; Uchida et al., 2011). Unless one is carefully and intensely focussing on a specific location, motion cues by nature attract attention to the stimulated visual event (Corbetta & Shulman, 2002). Moreover, adding motion transients to the change or its location may improve detection rates (see e.g. Klein et al., 1992; Scholl, 2000; Zheng & McConkie, 2010). Since changes in electronic speed limits lack motion transients for most drivers, adding them might possibly attenuate change blindness. However, motion cues may also become distractors. For example, when two changes happen simultaneously, change detection for the changing target is attenuated (O'Regan et al., 1999; Rensink et al., 2000). It is therefore uncertain whether motion cues such as commonly used flashing amber lights will attenuate or increase change blindness for changes in electronic speed limits.

Studies have also shown that it is more difficult to detect a change when already visible information changes, as compared to information that is added to a scene (for a review see Rensink, 2002). For example, Mondy and Coltheart (2000) found that when the meaning of a scene or object remains unaltered, changes to whole objects are identified more often than changes to objects which are part of a larger object. Similarly, Davies and Beeharee (2012) found that newly inserted objects on a smartphone screen are more often correctly identified than changes within on-screen objects. These findings are particularly interesting for electronic road signs, as road authorities may choose to either display speed limits on them continuously or only in case of deviations. The first approach would lead to continuously changing speed limits, which can be considered as an information change. The latter results in electronic signs which are alternately blank or displaying a speed limit. This can be considered an information addition.

3. Method

3.1 Experimental design

Based on the literature review described in the Theory section, adding motion signals and turning the change into an information addition have been identified as possible countermeasures and are described in more detail below. Both were assessed by showing participants a short video which represented a motorway equipped with three gantries displaying variable speed limits on electronic signs per driving lane. The video was shown fifteen times and was preceded by a practice video. To familiarise participants with the motorway and its surroundings, the first, experimental, video was displayed unchanged and viewed thirteen times (see also Harms & Brookhuis, 2016, and Martens & Fox, 2007). To prevent any interference from participants who might expect the change to happen in the last (15th) video, the change was introduced in the 14th video. In this video, the speed limits were changed from 100 km/h to 80 km/h on the second and the third gantries. To ensure that changes would be attributed to elements of the road and its surroundings, no other traffic was present in the videos. Video 15 consisted of a recollection test. Table 1 gives an overview of all speed limits encountered per video. Route-familiarity was promoted to resemble real-life conditions, as most journeys are driven on familiar roads (Dicke-Ogenia, 2012). This is relevant, as drivers who have driven a road repeatedly, have a tendency to shorten their glance duration for traffic signs. Thus, making them more prone to make change detection errors (Martens & Fox, 2007).

To detect whether participants noticed a change, an intentional approach – commonly used for change blindness paradigms – was used. With this approach, the observer is instructed to fully expect a change and devotes all available resources to

detecting it (cf. Simons & Mitroff, 2001). Despite all resources being allocated to the task, change blindness is generally found under these conditions (e.g. Galpin et al., 2009; Grimes, 1996; Lee et al., 2007; O'Regan et al., 2000; Rensink et al., 1997; Velichkovsky et al., 2002).

In a 2x3 design, change detection was measured for the type of change (Information Addition and Information Change), under three conditions of information discriminability (Control, Flash and Wave, see Table 2). For Information Addition, the electronic overhead signs were always left blank, unless the speed limit changed; in Information Change, the electronic overhead signs were always activated, hence depicting a speed limit on all of them (see Figure 1). The three conditions of information discriminability varied only in how the first, changed speed limit was displayed (see Table 1 for the speed limit order). In the control condition, this was displayed by solely depicting the speed limit itself; for Flash, it was shown with additional alternating amber flashing lights; for Wave, it appeared as if the depicted speed limit was moving in a wave-like manner as a row of pixels was blacked out while constantly moving from the top to the bottom of the sign and vice versa (see Figure 2). The second changed speed limit was displayed without additional motion transients, thus it was the same for all groups (see Figure 3). To ensure that all participant groups were equally able to detect changes, participants were assigned to one of the six groups based on age and gender, as some studies reported an age-related decline in the detection of changes (Caird et al., 2005; Costello et al., 2010; Rizzo et al., 2009; Wascher et al., 2012).

*Table 1. The four speed limits participants encountered per video. The first was displayed on a fixed roadside sign and the others on electronic signs on subsequent overhead gantries. For video 14, * is the first changed speed limit and ** is the second changed speed limit. Video 15 did not display any speed limits as it was a recollection test.*

	<i>Speed limit 1</i> roadside sign	<i>Speed limit 2</i> gantry 1	<i>Speed limit 3*</i> gantry 2	<i>Speed limit 4**</i> gantry 3
Video 1 - 13	100 km/h	100 km/h	100 km/h (see Figure 1)	100 km/h
Video 14	100 km/h	100 km/h	80 km/h (see Figure 2)	80 km/h (see Figure 3)

Table 2. The 2x3 design

		<i>Varieties of information discriminability</i>		
		Control	Flash	Wave
<i>Type of change</i>	Information Addition	Group 1	Group 2	Group 3
	Information Change	Group 4	Group 5	Group 6

3.2 Participants and procedure

Participants were recruited by means of invitations from both fellow participants and the researcher, including advertisements on the internet and an invitation on a birth announcement card. The experiment was successfully completed by 255 participants. In total 269 participants completed the experiment, though fourteen of them were excluded as they used a computer screen smaller than the video's resolution. The six groups of participants did not differ significantly with respect to age and gender (both classification criteria for group formation), as well as education, years of driving licence possession and amount of kilometres driven in the past twelve months.

Participants' age varied from 19 to 75 years ($M = 42.3$ years, $SD = 12.1$), and both male and female Dutch drivers participated (69.8% male and 30.2% female). All participants possessed a driving licence ($M = 22.5$ years, $SD = 12.1$) and had driven a passenger car for, on average, 18,500 kilometres in the past twelve months prior to the experiment ($SD = 18,800$). All reported normal or corrected to normal eyesight. Participants were not paid for their participation.

Participants were requested not to pause or to be assisted or disturbed during the experiment. Following a short questionnaire on participant characteristics and a self-paced practice video, participants were instructed that they would see fifteen videos of the same motorway from a driver's perspective. For videos 1 to 14, they were asked to imagine driving the car and to report all changes between the current and the previous videos. It was pointed out that the changes they would come across would be traffic-related and that the number of changes varied between participants ranging from several to none at all; actually all participants came across two changes in video 14. To report a change, participants pressed the spacebar. In accordance with Crundall (2012), the screen subsequently turned black while the video was stopped. Participants then described the change; reported that they had seen the change but failed to identify it; or reported pressing the spacebar accidentally. For video 15, participants had to recall several omitted roadside elements, including all speed limits. After viewing all 40-second videos, participants received a short follow-up questionnaire on the videos they had seen. The experiment took 20 minutes to complete. The study has been approved by the Ethical Committee of the Department of Psychology of the University of Groningen.

Figure 1. Screen shot of the second gantry in video 1 to 13, i.e. before the speed limit changes, for the two types of changes: Information Addition (top) and Information Change (bottom).

Figure 2. Screen shot of the second gantry depicting the changed speed limit under three conditions of information discriminability in video 14. From top to bottom: Control, Flash, and Wave.

Figure 3. Screen shot of the third gantry, depicting the second changed speed limit in video 14. This sign was the same for all groups.

3.3 Materials

3.3.1 Computer and videos

Participants accessed the experiment on their own computer through a website using a personal entry code. The website could be viewed on a Windows or Apple operating system using a mainstream web browser such as Internet Explorer, Firefox or Google Chrome. Internet access and a keyboard were required. The experiment was not suitable for smartphones or tablets.

The videos showed a forward view of the road ahead, and a navigation device was displayed in the lower right corner (see Figure 1-3). The video resolution required 1136 pixels wide and 640 pixels high. Dedicated software automatically gathered the screen resolution of the computer participants used and recorded space bar hits during video viewings. The responses were sampled with a precision of 1/10th of a second. The videos were equipped with car sounds, e.g. engine noise, to make the viewings more realistic. To ensure that participants could hear the audio signal, an audio test was embedded at the beginning of the experiment.

3.3.2 Questionnaire

The questionnaire finalising the experiment contained questions on the speed limits participants had encountered in the videos. Successive topics were recollection (had they noticed anything special about the speed limits in video 1 to 14?); expectation (what expectations did they have concerning possible variability in speed limits?); and finally recognition (had they seen the change?). These questions were also asked for the other omitted items in video 15. As participants may be inclined to say they have seen the change (even if they had not), the recognition question also included a plausible alternative. For this, it was suggested that there had been two groups. For example, in the case of the speed limits; one group for whom the speed limit on the gantries had always been 100 km/h and another group for whom the speed limit on the gantries had decreased from 100 km/h to 80 km/h. While in fact all participants belonged to the second group, they were asked to which group they thought they belonged and how confident they were of their response. For all omitted items it was suggested that it was possible to belong to a group that had encountered either several changes, or one change, or no change at all in video 14.

3.4 Measures

To detect whether participants noticed the two changes which occurred in video 14, change detection was measured in five ways. Detection accuracy (measure 1) was measured during videos 1 to 14. This included both detection as well as change identification, respectively measured by the amount of space bar presses and the descriptions of the detected changes. Simultaneously, reaction time was measured (measure 2). The third measure was part of a recollection task participants performed in video 15. In this video both the changed speed limits as well as a few other roadside elements that had not changed were omitted. The video stopped at each point where an item was omitted and a yellow circle marked the spot where the item had been present in all previous videos. Participants had to report what had been visible at that spot in video 14 and were instructed to guess when necessary (measure 3). They also reported how confident they were of their answer. The omitted items in video 15 included in consecutive order a roadside fixed speed limit sign, electronic speed limit signs on an overhead gantry, a part of the signposting, electronic speed limit signs on an overhead gantry, route information on a roadside variable message sign, electronic speed limit signs on an overhead gantry and a roadside billboard containing a traffic-related advertisement from a recent government campaign. The fourth and fifth measure were part of the final questionnaire, which included the question about recollection concerning the speed limits (measure 4) and the recognition question which explicitly asked participants whether they had seen the change (measure 5).

3.5 Data analysis method

Although screen sizes varied between participants (width from 1208 to 2560 pixels, height from 686 to 1440 pixels), ANOVA with post hoc Bonferroni revealed there were no significant differences between the six groups. Nevertheless, due to the variations in screen sizes, the exact time mark when the changes were visible in the video varied slightly per participant. To be able to compare reaction times between groups, normalised reaction times were calculated for both changes in video 14. To this end, participants' responses were measured from the start of the video to the moment they responded. These normalised reaction times were calculated as follows. Firstly, all accurate responses to the first and the second change were selected and separated based on participants' change identification responses and descriptive statistics were calculated per change. For the first change, the lowest response time ($RT_{\min}$) measured was 9.2s. The highest response time ($RT_{\max}$) was 22.9s ($M = 18.2s$, $SD = 2.4$). For the second change (which appeared at a later point in time in the video hence the longer response time), the lowest response time measured was 19.4s and the highest was 38.8s ($M = 34.7s$, $SD = 2.7$). Lastly, normalised reaction time (RT') scores were computed using feature scaling [$RT' = (RT - RT_{\min}) / (RT_{\max} - RT_{\min})$], independently for the first and the second change. Due to a technical error three participants were unable to stop video 14. These participants were removed from the analysis of response data for video 14, hence $n = 252$ for video 14.

4. Results

4.1 Detection accuracy

The first speed limit change in video 14 is what ultimately distinguished the six participant groups. Table 3 shows that for both Information Addition as well as Information Change all participants in the control condition responded accurately to this speed limit decrease, i.e. correctly detecting and identifying what had changed (measure 1). To reveal the effect of both the type of change and information discriminability on detection accuracy an ANOVA was performed, showing that detection accuracy of the first change was affected both by the interaction of the type of change together with information discriminability [$F(2,252) = 8.50$, $p < 0.001$] and by information discriminability itself [$F(2,252) = 3.86$, $p = 0.022$]. There was no main effect of the type of change. Whereas all participants in the control condition were able to detect the first change, this was not the case for the participants in the Flash and Wave condition. Post hoc tests using the Bonferroni correction showed that the decrease was statistically significant for Flash, $p = 0.042$, 95% CI[0.002, 0.161], though it was not for Wave, $p = 0.090$, 95% CI[-0.008, 0.152]. However, though there is an interaction effect with the type of change – Information Addition or Information Change – the addition of flashers clearly deteriorates the detection of the first changed speed limit. Both driver age as well as driver experience – years of driving licence possession and amount of kilometres driven in the past twelve months – did not affect detection accuracy for Flash, Wave, Information Addition, Information Change and their combinations. Detection of the second change was not influenced by any of the experimental groups; there were no interaction effect nor main effect of either the type of change or information discriminability.

Table 3. Detection accuracy, i.e. correct detections and identifications of what had changed, for the first speed limit change per group (Information Addition and Information Change under three conditions of information discriminability). When testing with an α of 0.05, post hoc tests using the Bonferroni correction showed that the decreased detection accuracy was only statistically significant for Flash.

		Varieties of information discriminability			
		Control	Flash	Wave	Total
Type of change	Information Addition	100.0%	86.4%	100%	95.4%
	Information Change	100.0%	97.6%	84.2%	94.2%
Total		100.0%	91.9%	92.8%	

Only 2.0% of the participants failed to respond to any of the changes; they neither detected the speed limit decrease on the second nor on the third gantry. The questionnaire concluding the experiment confirmed that these participants indeed failed to notice them; none of them noticed anything particular about the speed limits (measure 4) and they all stated they belonged to the group of participants for whom the speed limit on the gantries had always been 100 km/h (measure 5) and they were certain to very certain about this ($M = 4.20$ on a 5-point Likert scale, $SD = 0.45$).

4.2 Reaction time

Both the type of change and the information discriminability, as well as their interaction affected the mean RT' for the first change in video 14 (measure 2) confirmed by ANOVA; $F(1,239) = 9.30$, $p = 0.003$; $F(2,239) = 6.45$, $p = 0.002$; $F(2,239) = 20.82$, $p < 0.000$, respectively. Participants for whom a speed limit was added to a blank sign, showed shorter mean RT' scores than participants for whom the speed limits had merely changed from one speed limit to another. Figure 4 displays mean RT's scores per group, indicating the complicating effect that information discriminability has. On average participants in the Flash condition elicited longer reaction times than did participants in the control and Wave conditions. Post hoc tests using the Bonferroni correction revealed that this difference was statistically significant for both Flash vs Control, $p = 0.002$, 95% CI[0.026, 0.147], and Flash vs Wave, $p = 0.005$, 95% CI[0.020, 0.143]. The mean RT' scores of participants in the control and Wave conditions did not vary significantly. For the second change solely a statistically significant interaction effect was found, $F(2,200) = 11.06$, $p < 0.000$. There were no main effects for type of change or information discriminability.

As expected, reaction times increased with participants' age for both Information Addition as well as Information Change, though this correlation was not strong, $r = .20$, $n = 126$, $p = .027$, and $r = .28$, $n = 114$, $p = .003$, respectively. As age and years of driving licence possession are strongly correlated, $r = .95$, $n = 255$, $p < .001$, it is not surprising that for Information Change, participants who possessed their driving licence for a longer period of time also displayed longer reaction times, $r = .26$, $n = 114$, $p = .005$. However, this correlation was not found for Information Addition, which may suggest that driving experience of participants explained a quicker detection of change in this condition. For information discriminability, the correlation with age was only significant for Wave, $r = .24$, $n = 77$, $p = .039$. This means that reaction time performance was comparatively better for older participants in the control condition as well as when using Flash. Driving experience, in terms of years of driving licence possession, did not correlate with reaction time for Control, Flash or Wave. Nor gender nor the amount of kilometres travelled in the past twelve months correlated with reaction time under any of the conditions.

Figure 4. Mean normalised reaction time (RT') for detection of the first change for information addition (IA) and information change (IC) under three conditions of information discriminability. Error bars show 95% confidence intervals.

4.3 Speed limit recollection

Figure 5 shows that while viewing video 15, only 34.9% of all participants accurately recollected the sequence of speed limits shown in video 14 (measure 3). Of this sequence, only the last two speed limits had changed (from 100 km/h to 80 km/h). These were recollected correctly by respectively 88.6% and 92.2% of the participants (see Figure 6). There were no interaction effects nor main effects of either the type of change or information discriminability for these third and fourth speed limit, nor for the first speed limit.

In contrast, Figure 6 points out that difficulties with recollecting the correct sequence of speed limits appear to be mostly due to false recollection of the first electronic speed limit (which was the second speed limit in the sequence). This speed limit was recollected correctly by only 45.1% of the participants. The relatively low correct recollection rate of this first electronic speed limit may partially be explained by the experimental groups in which participants had been divided. As the first electronic speed limit never changed, it was left blank for half of the participants – that is, all participants belonging to one of the Information Addition groups – as in their case there was no need to display a new speed limit since the previously stated speed limit was still valid. These participants displayed somewhat more difficulties with recollecting the right speed limit (38.9% correct) compared to participants out of one of the Information Change groups (52.1% correct), though marginally significant ($F(1,252) = 3.53$, $p = 0.062$). There was no main effect of information discriminability, although the test did show a strong interaction effect of the type of change and information discriminability, $F(2,252) = 6.05$, $p = 0.003$, explaining differences in the recollection rate of the first electronic speed limit.

Figure 5. Recollected speed limit sequences in video 15. The correct sequence is 100 km/h, 100 km/h, 80 km/h, and 80 km/h.

Figure 6. Recollection for subsequent speed limits in video 15. The fixed sign depicted the fixed roadside speed limit and matrix 1 to 3 depicted the subsequent electronic speed limits on overhead gantries.

4.4 Expectancy

Whereas all participants knew that something traffic related would change, expectations about *what* would change varied widely. Almost all participants (94.5%) had expected that the electronic speed limits would change, including all participants who failed to respond to the changes at all. Most people (91.8%) also expected that the text on the roadside variable message sign would change. These expectations of changeability were much lower for other traffic signs; 58.0% for the fixed signposting and 37.6% for the traffic-related advertisement sign. This suggests that traffic signs with a dynamic appearance indeed increase expectations regarding the likelihood that information on them might change. In short, they do not only look dynamic, but most people also expect them to be so.

5. Discussion

Despite promising reviews in the existing literature, the countermeasures assessed were incapable of effectively aiding change detection. Turning the change into an addition of information yielded mixed results. Although it did not aid change detection – contrary to other change blindness studies (for a review see Rensink, 2002) – it appeared beneficial for reducing people's response time. However, the lack of repetition also made it increasingly difficult for drivers to memorise the correct speed limit. For speed limits, a beneficial effect on response time does not outweigh a negative effect on recall, as the retention of information is the final step in McGuire's (1968) information processing steps to obtain compliance.

Even more troublesome was the finding that motion transients designed to attract attention to message signs actually eroded detection of the changed speed limit. Up to 13.6% of the participants (Information Addition x Flash) appeared unable to perceive the speed limit once the amber flashing lights were activated. Together with the longer reaction times for those who did detect the change, participants appear to be distracted by the addition of motion in our study. While Klein and colleagues (1992), Scholl's (2000) and Zheng and McConkie's (2010) successful motion additions occurred prior to or together with the change, our additional motion cues highlighted the location post-change. The presence of the attention-demanding, artificially-added motion cues in our study may have hindered the processing of information contained in the signs. As this is a necessary step to be able to detect the change, it resulted in a certain amount of change blindness.

Based on the current study it is hard to estimate the amount of change blindness to expect under real-life conditions. For example, in their driving simulator study, Harms and Brookhuis (2016) reported a considerable amount of change blindness for changes in electronic speed limits in a situation that is – from a traffic engineering point of view – comparable with that of Group 4 (Information Change x Control). In comparison, the present study found 100% detection. This difference may be explained by some limitations of the present study. First of all, the study's ecological validity is limited. As driving a (simulator) car is more attention-demanding than viewing videos, it is likely that one may find greater amounts of change blindness in a more realistic setting. Secondly, the instruction to look for changes presumably attenuated change blindness. This instruction may have primed the participants, which aids change detection (Landman et al., 2003; Niedenthal et al., 2001; Pearson & Schaefer, 2005; Wallis & Bülthoff, 2000). Nevertheless, the present study confirms that even when changes are expected they can still be missed, as stated by e.g. Simons and Mitroff (2001). Finally, the remote setting of the experiment resulted in less control over the apparatus and the circumstances in which the experiment had been executed. This has been partly resolved by automatically gathering information on the screen size of the computer participants used to view the videos; by clearly instructing participants how to avoid distraction during the duration of the experiment; and by giving participants the opportunity to report about any aberrant circumstances and any technical failures that occurred during the experiment. Using an internet-based platform enabled more drivers from all over the Netherlands to participate in the experiment.

6. Conclusion

Using flashers and waves to attract attention to electronic signs seems to deteriorate people's ability to process the information contained in the signs. These findings may shed a new light on how flashing amber lights affect driver behaviour. Whilst having the potential to alert drivers to dangerous traffic conditions down the road, they may be counterproductive in attracting attention to any additional messages. The findings support the point of view taken by the Finnish National Road Administration, stating that the use of flashers in speed limit signs has to be well-motivated and should be used in a very limited way for regulatory messages; for

instance, only for queue-tail protection (Rämä et al., 2004). As our study did not result in any appropriate measures to counter change blindness in electronic speed limits, we suggest additional research to improve drivers' ability to detect these changes. Additionally, further research is needed to assess the extent to which drivers perceive the speed limits contained in electronic signs when the flashers are activated in practice. This is important, as amber flashing lights are already part of many road authorities' toolbox and are used especially in safety critical situations.

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References

- Al-Gadhi, S. A. H., Abid Naqvi, S., & Abdul-Jabbar, A. S. (1994). Driver factors affecting traffic sign detection and recall. *Transportation Research Record*, (1464), 36-41.
- Caird, J. K., Edwards, C. J., Creaser, J. I., & Horrey, W. J. (2005). Older driver failures of attention at intersections: Using change blindness methods to assess turn decision accuracy. *Human Factors*, 47, 235-249. doi:10.1518/0018720054679542
- Charlton, S. G., & Starkey, N. J. (2013). Driving on familiar roads: Automaticity and inattention blindness. *Transportation Research Part F: Traffic Psychology and Behaviour*, 19, 121-133. doi:10.1016/j.trf.2013.03.008
- Corbetta, M. & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature reviews neuroscience*, 3, 201-215. doi:10.1038/nrn755
- Costello, M. C., Madden, D. J., Mitroff, S. R., & Whiting, W. L. (2010). Age-Related Decline of Visual Processing Components in Change Detection. *Psychology and Aging*, 25, 357-368. doi:10.1037/a0017625
- Crundall, D. (2012). Predicting change: a more robust measure of hazard perception? Paper presented at 5th International Conference on Traffic and Transport Psychology.
- Davies, T., & Beeharee, A. (2012). The case of the missed icon: Change blindness on mobile devices. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*, ACM, New York, NY, USA. pp. 1451-1460. doi: 10.1145/2207676.2208606
- Dicke-Ogenia, M. (2012). *Psychological aspects of travel information presentation: A psychological and ergonomic view on travellers' response to travel information* (PhD dissertation, Technische Universiteit Delft, Delft, The Netherlands). doi:10.4233/uuid:bb928d00-fd70-420a-8536-462bb22368d9
- Galpin, A., Underwood, G., & Crundall, D. (2009). Change blindness in driving scenes. *Transportation Research Part F: Traffic Psychology and Behaviour*, 12(2), 179-185. doi: 10.1016/j.trf.2008.11.002
- Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. Akins (Ed.), *Perception* (pp. 89-110). New York: Oxford University Press. doi:10.1093/acprof:oso/9780195084627.003.0004
- Harms, I. M., & Brookhuis, K. A. (2016). Dynamic traffic management on a familiar road: Failing to detect changes in variable speed limits. *Transportation Research Part F: Traffic Psychology and Behaviour*, 38, 37-46. doi:10.1016/j.trf.2016.01.005

- Hoogendoorn, R. G., Harms, I. M., Hoogendoorn, S. P., & Brookhuis, K. A. (2012). Dynamic maximum speed limits: Perception, mental workload and compliance. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2321, 46-54. doi:10.3141/2321-07
- Johansson, G., & Backlund, F. (1970). Drivers and road signs. *Ergonomics*, 13(6), 749-759. doi:10.1080/00140137008931202
- Johansson, G., & Rumar, K. (1966). Drivers and road signs: A preliminary investigation of the capacity of car drivers to get information from road signs. *Ergonomics*, 9(1), 57-62. doi: 10.1080/00140137008931202
- Klein, R., Kingstone, A., & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp. 46-65). New York: Springer. doi:10.1007/978-1-4612-2852-3_4
- Lajunen, T., Hakkarainen, P., & Summala, H. (1996). The ergonomics of road signs: Explicit and embedded speed limits. *Ergonomics*, 39(8), 1069-1083. doi:10.1080/00140139608964528
- Landman, R., Spekrijse, H., & Lamme, V. A. F. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research*, 43(2), 149-164. doi:10.1016/S0042-6989(02)00402-9
- Lee, Y., Lee, J. D., & Boyle, L. N. (2007). Visual attention in driving: The effects of cognitive load and visual disruption. *Human Factors*, 49(4), 721-733. doi: 10.1518/001872007X215791
- Luoma, J. (1991). *Evaluations of validity of two research methods for studying perception of road signs* No. UMTRI-91-15). Ann Arbor: The University of Michigan Transportation Research Institute.
- Luoma, J., & Rämä, P. (1998). Effects of variable speed limit signs on speed behaviour and recall of signs. *Traffic Engineering and Control*, 39(4), 234-237.
- Martens, M. H., & Fox, M. R. J. (2007). Do familiarity and expectations change perception? drivers' glances and response to changes. *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(6), 476-492. doi:10.1016/j.trf.2007.05.003
- McGuire, W.J. (1968). Personality and attitude change: an information-processing theory. In: A.G. Greenwald, T.C. Brock & T.M. Ostrom (Eds.), *Psychological foundations of attitudes* (pp.171-196). San Diego, CA: Academic Press.
- Mondy, S., & Coltheart, V. (2000). Detection and identification of change in naturalistic scenes. *Visual Cognition*, 7(1-3), 281-296. doi:10.1080/135062800394810
- Muller, Th.H.J., & Verweij, C.A. (1991). *Onderzoek verkeersregeling Hoofdweg/ Pr. Alexanderlaan Rotterdam*. VK4200.304. Delft: Technische Universiteit Delft, Faculteit der Civiele Techniek, Vakgroep Verkeer.
- Niedenthal, P. M., Brauer, M., Halberstadt, J. B., & Innes-Ker, Å H. (2001). When did her smile drop? Facial mimicry and the influences of emotional state on the detection of change in emotional expression. *Cognition and Emotion*, 15(6), 853-864. doi: 10.1080/02699930143000194
- Nissan, A. (2010). *Evaluation of variable speed limits: Empirical evidence and simulation analysis of stockholm's motorway control system* (PhD dissertation, Royal institute of Technology, Stockholm, Sweden).
- O'Regan, J. K., Deubel, H., Clark, J. J., & Rensink, R. A. (2000). Picture changes during blinks: Looking without seeing and seeing without looking. *Visual Cognition*, 7(1), 191-211. doi:10.1080/135062800394766
- O'Regan, J. K., Rensink, R. A., & Clark, J. J. (1999). Change-blindness as a result of "mudsplashes". *Nature*, 398, 34-34. doi:10.1038/17953

- Pearson, P. M., & Schaefer, E. G. (2005). Toupee or not toupee? the role of instructional set, centrality, and relevance in change blindness. *Visual Cognition*, 12(8), 1528-1543. doi:10.1080/13506280444000814
- Rämä, P., Schirokoff, A., & Luoma, J. (2004). *Practice and deployment of variable message signs (VMS) in viking countries—potential for harmonization*. Helsinki: Finnish National Road Administration.
- Rämä, P. (2001). *Effects of weather-controlled variable message signing on driver behaviour* (PhD dissertation, Helsinki University of Technology, Espoo, Finland).
- Rensink, R. A. (2002). Change detection. *Annual Review of Psychology*, 53, 245-277. doi:10.1146/annurev.psych.53.100901.135125
- Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, 8(5), 368-373. doi:10.1111/j.1467-9280.1997.tb00427.x
- Rensink, R. A., O'Regan, J. K., & Clark, J. J. (2000). On the failure to detect changes in scenes across brief interruptions. *Visual Cognition*, 7(1), 127-145. doi:10.1080/135062800394720
- Rizzo, M. D., Sparks, J. D., McEvoy, S. D., Viamonte, S. M., Kellison, I. L., & Vecera, S. P. (2009). Change blindness, aging, and cognition. *Journal of Clinical & Experimental Neuropsychology*, 31, 245-256. doi:10.1080/13803390802279668
- Scholl, B. (2000). Attenuated change blindness for exogenously attended items in a flicker paradigm. *Visual Cognition*, 7(1-3), 377-396. doi:10.1080/135062800394856
- Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences*, 1(7), 261-267. doi:10.1016/S1364-6613(97)01080-2
- Simons, D. J., & Mitroff, S. R. (2001). The role of expectations in change detection and attentional capture. In L. R. Harris, & M. R. M. Jenkin (Eds.), *Vision and attention* (pp. 189-207). New York: Springer Verlag. doi:10.1007/978-0-387-21591-4_10
- Uchida, N., De Waard, D., & Brookhuis, K. A. (2011). Countermeasures to prevent detection failure of a vehicle approaching on collision course. *Applied Ergonomics*, 42(4), 540-547. doi:10.1016/j.apergo.2010.09.007
- Van Nes, N., Brandenburg, S., & Twisk, D. (2010). Improving homogeneity by dynamic speed limit systems. *Accident Analysis & Prevention*, 42(3), 944-952. doi:10.1016/j.aap.2009.05.002
- Velichkovsky, B. M., Dornhoefer, S. M., Kopf, M., Helmert, J. R., & Joos, M. (2002). Change detection and occlusion modes in road-traffic scenarios. *Transportation Research Part F: Traffic Psychology and Behaviour*, 5(2), 99-109. doi:10.1016/S1369-8478(02)00009-8
- Wallis, G., & Bühlhoff, H. (2000). What's scene and not seen: Influences of movement and task upon what we see. *Visual Cognition*, 7(1-3), 175-190. doi:10.1080/135062800394757
- Wascher, E., Schneider, D., Hoffmann, S., Beste, C., & Sängner, J. (2012). When compensation fails: Attentional deficits in healthy ageing caused by visual distraction. *Neuropsychologia*, 50, 3185-3192. doi:10.1016/j.neuropsychologia.2012.09.033
- White, C. B., & Caird, J. K. (2010). The blind date: The effects of change blindness, passenger conversation and gender on looked-but-failed-to-see (LBFTS) errors. *Accident Analysis & Prevention*, 42(6), 1822-1830. doi:10.1016/j.aap.2010.05.003
- Zheng, X. S., & McConkie, G. W. (2010). Two visual systems in monitoring of dynamic traffic: Effects of visual disruption. *Accident Analysis & Prevention*, 42(3), 921-928. doi:10.1016/j.aap.2009.10.001