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Published in:
Transportation Research. Part F: Traffic Psychology and Behaviour

DOI:
[10.1016/j.trf.2018.09.011](https://doi.org/10.1016/j.trf.2018.09.011)

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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2019

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Harms, I. M., Dijksterhuis, C., Jelijs, L. H., de Waard, D., & Brookhuis, K. A. (2019). Don't shoot the messenger: traffic-irrelevant messages on variable message signs (VMSs) might not interfere with traffic management. *Transportation Research. Part F: Traffic Psychology and Behaviour*, 65, 564-575. <https://doi.org/10.1016/j.trf.2018.09.011>

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Don't shoot the messenger: Traffic-irrelevant messages on variable message signs (VMSs) might not interfere with traffic management



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ARTICLE INFO

Article history:

Received 18 December 2016

Received in revised form 14 September 2018

Accepted 14 September 2018

Available online 27 September 2018

Keywords:

Variable message sign

Compliance

Advertisement

Repeated practice

Recall

Automaticity

ABSTRACT

Road authorities struggle with the question whether variable message signs (VMSs) should exclusively be used for traffic management or could also be used to display traffic-irrelevant messages, such as mottos or commercial advertisements. The current study assesses behavioural responses to a critical route instruction displayed on the same VMS that previously displayed a variety of traffic-irrelevant messages. For this, thirty-two participants were divided between a control group and an experimental group (the advertisements group). In a driving simulator, all were familiarised with the same route by driving a VMS-equipped motorway nine times. For the advertisements group, up to drive 8, this VMS displayed various advertisements. Whereas for the control group it was blank. In the 9th drive, the VMS displayed a critical detour message for all participants. This critical route instruction – informing drivers to take the nearest exit – resulted in compliant driver behaviour in the advertisements group. In addition, they only reduced speed marginally to increase the time to process the VMS text. The control group, on the contrary, displayed a much sharper speed reduction; though the instruction only moderately altered motorway exit behaviour. What is more, the 31% ($n = 4$) of the advertisements group who complied with the critical route instruction subsequently failed to recall this message (recalling an advertisement instead). In conclusion, this study provides evidence that displaying traffic-irrelevant messages on VMSs might not interfere with traffic management; provided the format of said messages is in accordance with ergonomic VMS guidelines as used in this study. It is proposed that due to repeated exposure to various VMS texts, reading the sign has been practised to the extent that little to no conscious deliberation was required. As a result, recall of what was seen, proved to be an inadequate proxy for assessing driver behaviour. This study shows that conscious attention might not be a prerequisite for compliance. Furthermore, it suggests that continuous variability in objects in the traffic environment may become part of a subconscious monitoring process, as long as they have been sufficiently practised.

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1. Introduction

Road authority experts have been discussing for years whether to display messages on VMSs when they are not in use for traffic management (for an overview see Mitchell, 2011). The main function of VMSs is to communicate traffic management messages to the public. Currently these electronic signs feature texts and/or pictograms, mainly concerning traffic information, road works, weather related information or (in some countries) road safety motto messages. They are – in theory – also capable of displaying commercial advertisements. To our knowledge, currently VMSs are not used for commercial advertisements, despite or perhaps because of the ongoing discussion. Typically, proponents of advertisements on VMSs stress the economic advantage of advertising which alleviates the (maintenance) costs of these expensive signs. The opponents, on the other hand, argue that there may be a possible threat of reduced attention for VMSs in the long-term once they start displaying traffic-irrelevant messages alternating with traffic-relevant information. Hence, they propose VMSs should remain blank when not in use for traffic management. Their main argument is their concern that drivers will become jaded, ignore future messages and risk missing critical information (Mitchell, 2011). For example, Dudek (2008) advised against advertisements as he feared they would make drivers change blind; a commonly used argument referring to the inability to timely detect changes around us that are readily visible (for reviews see Rensink, 2002; Simons & Levin, 1997).

In some countries guidelines are in place that explicitly advice against the display of advertisements on VMSs (e.g. FHWA, 2012; Rood, Hillen, Methorst, & Poorterman, 2012). In previous years several European national road authorities, united in the Conference of European Directors of Roads (CEDR), also agreed to refrain from displaying advertisements. Nevertheless, research on the matter appears to be lacking in the literature. This, despite the fact that advertising on VMSs is not new (Kolb, 1995) and arguments of both proponents as well as opponents being present (Mitchell, 2011). To answer the question whether commercial advertisements are a viable alternative to leaving the VMS blank, several sub questions must be answered. The aim of the current study is to provide one of these answers. The question addressed in this study is how traffic-irrelevant messages on a VMS affect the perception of, and subsequent compliance with, a traffic management message displayed on the same VMS.

1.1. Traffic safety: Avoiding distraction by advertisements

The term VMS covers a wide variety of electronic or dynamic message signs available to road authorities. Although implications of this article may be applicable to a broader range of VMSs, in this article we refer to large electronic signs placed on overhead gantries as displayed in Fig. 1. One prerequisite for non-traffic related messages on VMSs should be that they do not distract drivers. As research on driver distraction by traffic-irrelevant messages on VMSs is lacking, it is useful to examine what is known about messages on VMS in relation to driver distraction. First of all, traffic management messages themselves should meet several cognitive-ergonomic principles in order not to distract drivers too much (Dicke-Ogenia & Brookhuis, 2008). When the information density on a VMS is high, drivers will need (too) much time to read the message (Roskam et al., 2002). This may result in an unacceptable long period of inattention to the road ahead, or compensatory behaviour such as drivers slowing down, or incomplete to no information transfer at all (e.g. Erke, Sagberg, & Hagman, 2007). Cognitive-ergonomic aspects of VMS messages in general are embedded in various road authority-issued VMS guidelines, such as from the EU, The Netherlands and New South Wales, Australia (Arbaiza & Lucas-Alba, 2012; Rijkswaterstaat, 2012; Rood et al., 2012; RTA, 2010).

Another type of VMS message that is prevalent in some countries and not part of traffic management, is the road safety motto or slogan. However, as far as known, no research on distracting effects of these messages has been carried out (SWOV, 2012). Limited research has been done on possible beneficial effects of road safety messages on VMS (Jamson & Merat, 2007; Schroeder & Demetsky, 2010; Tay & de Barros, 2010). All compared the display of blank VMS screens with road safety



Fig. 1. Example of an overhead VMS in real-life (left) and in the driving simulator (right), informing drivers they have to deviate from their route. Translations of the VMS texts are “A27 to Breda is closed. [Bridge] Malfunction. Breda follow Rotterdam” (left) and “A31 closed after Bergdorp. Accident. Oostdorp follow Bergdorp” (right).

messages in either quasi-experimental field studies or driving simulator studies. None of them found noteworthy safety benefits on either longitudinal or lateral driving behaviour, the parameters, that have been related to distraction by some researchers (e.g. Chattington, Reed, Basacik, Flint, & Parkes, 2009; Young et al., 2009). In conclusion, it appears that research on driver distraction caused by VMSs has predominantly been focussed on ergonomic aspects of messages rather than their semantic content (such as traffic management information versus road safety messages or commercial advertisements).

Content-related research on driver distraction by commercial advertisements on roadside billboards, however, is abundant. Various studies reported that specifically advertisements which involve motion, or provoke an emotional reaction, or are located in the central visual field, or resemble traffic-relevant information, may result in driver distraction (Beijer, Smiley, & Eizenman, 2004; Chattington et al., 2009; Crundall, Van Loon, & Underwood, 2006; Holahan, Culler, & Wilcox, 1978; Megías et al., 2011; SWOV, 2012). Moreover, the presence of advertisements can be associated with changes in visual attention as well as a reduced awareness to traffic signs (Edquist, Horberry, Hosking, & Johnston, 2011; Young et al., 2009). However, based on their meta study, Decker et al. (2015) conclude that not all roadside advertisements are visually distracting. Moreover, they found that in general advertisement-related distraction appeared to be minor. Research shows that this may even be the case when the advertisements are placed on, or immediately below, direction signs (Kaber et al., 2015; Metz & Krüger, 2014; Pankok, Kaber, Rasdorf, & Hummer, 2015). Pankok et al. (2015) and Kaber et al. (2015) studied the effects of commercial logo signs on motorways under various conditions of complexity. These signs display logos of businesses accompanied by an exit number to reach them. In their driving simulator studies only minor differences were found in driver visual behaviour between logo signs and directional signs, which did not translate into degradations of vehicle control. This finding is underpinned by Metz and Krüger's (2014) study on long-term effects of commercial advertisements on supplementary signs below direction signs. These are allowed in Germany since 2005. Metz and Krüger reported no effects of distraction or other negative side-effects of these commercial advertisements. Altogether, this is in line with Decker et al. (2015). They reported that drivers were capable of regulating the amount of visual attention spent on non-traffic related objects, based on the demands of their driving task. As yet, there are no reasons to assume that different principles apply to commercial advertisements than to other VMS messages such as traffic information or road safety messages. An additional advantage of commercial advertisements on VMSs compared to billboards, is that they can be removed when traffic conditions demand more driver attention.

1.2. Traffic flow: Reduced attention for traffic signs

Based on change blindness theory it is indeed to be expected that blank, inactive signs preceding a critical VMS message are to be favoured over active signs (for a review see Rensink, 2002). For example, Mondy and Coltheart (2000) found that changes to whole objects are identified more often than changes to objects which are part of a larger object. They used the flicker paradigm, in which consecutive pictures are divided by a brief blank. Davies and Beeharee (2012) used a variety of visual disruptions. Similarly, they found that newly inserted objects on a smartphone screen are more often correctly identified than changes within on-screen objects. However, research using electronic road signs did not find a meaningful difference between an inactive or an active sign preceding a change (Harms & Brookhuis, 2017; Jamson & Merat, 2007).

Part of the concern that drivers may become change blind or jaded, lies in the fact that over time drivers become familiar with advertisements on VMSs. Recent research on repeated exposure to non-traffic related information on VMSs is the study by Jamson and Merat (2007). They varied the concentration of road safety messages amidst blank VMSs which drivers were exposed to before arriving at a VMS displaying a critical, traffic relevant message. Repeatedly displaying the same two road safety messages on 24 consecutive VMSs indeed made drivers jaded with their content – or change blind –, resulting in an inferior response to critical information. However, this inferior response resembled responses from drivers for whom all previous VMSs had been blank. What is even more interesting is that variation – in this case alternately passing VMSs that either displayed the road safety message or the blank screen – actually increased driver alertness for the critical information. This increase in alertness allowed drivers to react more appropriately.

In general, several studies have shown that drivers who have become familiar with a specific road tend to pay less attention to traffic signs along this road. Their fixation duration for traffic signs shortens and drivers who have become habituated may even become blind for changes in traffic signs. This is the case for both static roadside signs as well as electronic overhead signs (Charlton & Starkey, 2013; Harms & Brookhuis, 2016; Martens & Fox, 2007). This inattention for traffic signs should perhaps not be attributed to the signs themselves. Instead, the tendency of drivers to mind wander or drive without awareness when increasingly familiar with a route should be taken into account (Charlton & Starkey, 2013; Yanko & Spalek, 2013). This tendency may prevent them from paying enough attention to the driving task. Nevertheless, Jamson and Merat (2007) found that even after repeated exposure drivers kept looking at VMSs. The shortened gaze durations over time that Jamson and Merat reported, are consistent with the reduced gaze durations Martens and Fox (2007) found for traffic signs, when drivers became more familiar with them. The gaze patterns suggest that the main concern for route-familiar drivers with variable signs may not be that drivers fail to look at them, but that drivers fail to see the information presented on them due to strong expectations they may hold.

The current study is a first attempt to disclose possible negative effects that repeatedly displaying traffic-irrelevant messages may have on the perception of, and subsequent compliance with, traffic-relevant messages for route-familiar

drivers. To ensure the focus lies on familiarisation and expectations instead of driver distraction, the amount of distraction induced by the design of the traffic-irrelevant messages should not exceed the level that is accepted for traffic management messages. Hence their design must meet the same design principles as regular, relevant, VMS messages (Kroon et al., 2016; Rijkswaterstaat, 2012). Based on the literature mentioned above, we hypothesised that repeatedly displaying safety slogans and commercial advertisements on a VMS would render route-familiar drivers less able to perceive a critical route instruction displayed on the same VMS. Hence, it is expected they are unable to behave appropriately.

2. Method

2.1. Experimental design

Participants were divided into two groups; an experimental group who encountered advertisements on a variable message sign (VMS) on an overhead gantry – which will be referred to as the advertisements group – and a control group for whom the sign was left blank during the same drives. All participants consecutively drove the same road ten times in a driving simulator to become familiar with the route. Prior to driving, participants filled out a demographic questionnaire and received a general instruction on the experiment. They then engaged in driving the same motorway multiple times. The first drive consisted of a practice drive in which the VMS was left blank. This was the same for all participants. For the subsequent drives two to eight, the VMS display differed between the control group and the advertisements group. For the control group the VMS was left blank during these drives. In contrast, for participants in the advertisements group the VMS was always on while displaying a variety of advertisements (which are shown in Fig. 2 together with the critical route instruction). To mimic a possible future scenario that would involve comparatively more commercial than road safety advertisements on VMSs, the advertisements on display – one advertisement per drive – consisted of two types of commercial advertisements (both displayed thrice) and one road safety message (displayed once). These appeared in a fixed order to ensure the effect on memory would be the same for all participants in the advertisements group.

A critical route instruction appeared on the VMS during the ninth drive. The same message was used for all participants. It informed them that in order to arrive at their destination they had to take the nearest exit as the road was closed due to an accident. This was an aberration from the route taken in all previous drives. Exiting the motorway constituted the behavioural response to acknowledge the critical route instruction was perceived. Additionally, recall and recognition of the critical route instruction were assessed. Recall consisted of an embedded recall task in drive ten – the final drive – in which all participants had to recall what had been displayed on various electronic signs in the previous drive (including the VMS displaying the critical route instruction). Recognition had been part of the questionnaire that finalised the experiment. This questionnaire also included questions about expectations. To prevent the VMS being singled out in the recall and recognition tasks and to simulate natural motorway driving in the Netherlands, the motorway had been equipped with both the VMS as well as electronic speed limits throughout the experiment. The experimental design and the timing of all manipulations are explained in Table 1.



Fig. 2. The four varieties of the VMS message. Top left: the critical route instruction (“A31 closed after Bergdorp. Accident. Oostdorp follow Bergdorp”). Top right: the road safety message (“Wear a seatbelt, in the backseat as well. This is how you get home”). Bottom: both commercial advertisements. Left the ad of a nation-wide chemist’s chain (“DA, that is the chemist’s, the friendly specialist. DA”). Right the ad of a nation-wide supermarket chain (“It is the ‘hamster weeks’ again at Albert Heijn”).

Table 1

Overview of the experimental design. Q₁ = demographic questionnaire. P = practice drive. B = VMS is blank. A₁ = VMS shows advertisement of a nation-wide supermarket chain. A₂ = VMS shows advertisement of a nation-wide chemist’s chain. A₃ = VMS shows road safety slogan. I = VMS shows critical route instruction. R = recall task. Q₂ = final questionnaire including expectation and recognition.

Drive #		1[P]	2	3	4	5	6	7	8	9	10[R]	
Control group	Q ₁	B	B	B	B	B	B	B	B	I	B	Q ₂
Advertisements group	Q ₁	B	A ₁	A ₂	A ₁	A ₃	A ₂	A ₁	A ₂	I	B	Q ₂

2.2. Participants and procedure

Participants were recruited on the proviso they had held their driving licence for at least five years and had driven in excess of 5000 km in the past twelve months ($M = 13,000$, $SD = 8200$). Thirty-two participants completed the experiment; one more participant withdrew with symptoms of simulator sickness and was therefore excluded from the experiment. Fifteen male and seventeen female Dutch drivers, aged 23–62 years ($M = 32.3$, $SD = 11.7$) participated; all reported normal or corrected to normal eyesight. Participants were randomly assigned to either the control group or the experimental (advertisements) group resulting in equally large groups. There was no statistically significant difference between these groups with respect to age, gender, education, years of driving licence possession and amount of kilometres driven in the past twelve months.

Participants were told that the aim of the experiment concerned the familiarisation process with a new route. It was pointed out that participants would drive to the same destination several times, without revealing the exact number of drives or the fact that the route to this destination would change during the experiment. Instead they were given route instructions prior to driving and were prompted to use the road signage in order to arrive at their destination. Participants were asked to drive as they normally would and afterwards all participants reported they had done so accordingly. After finishing all drives, participants filled out a brief questionnaire on what they had encountered while driving. The experiment took approximately 1.5 h to complete, after which participants were paid for their participation. The study has been approved by the Ethical Committee of the Department of Psychology of the University of Groningen.

2.3. Materials

Due to lack of availability in the real world, commercial advertisements on VMSs had to be simulated. Previous studies have shown that visual attention in real-road driving is comparable to simulated driving (Underwood, Crundall, & Chapman, 2011; Wang et al., 2010). The current study was conducted using the University of Groningen's STSoftware driving simulator. It consists of a fixed-base car mock-up, allows participants a 280° view of the driving environment and is capable of simulating fully interactive traffic. Both the software and the simulator have been described in more detail by Van Winsum and Van Wolfelaar (1993) and De Waard, Dijksterhuis, and Brookhuis (2009), respectively.

The simulated route was a 9 km long motorway, which was equipped with roadside direction signs – necessary to follow the regular route – and eight gantries depicting the speed limit on electronic signs. Moreover, the fourth gantry was also fitted with a large overhead VMS. In the ninth drive it displayed a message informing all participants they had to deviate from their regular route and take another exit (see Fig. 1, right). The speed limit was set at 80 km/h, similar to Harms and Brookhuis (2016). In order to prevent confounding effects of changes in other electronic road signs, all electronic speed limits were fixed throughout the experiment. The VMS was located 273 m before this exit and could be seen well in advance. The advertisements and the road safety message used for the advertisements group were slogans well-known to the public. All VMS messages followed the format of a traffic management message in accordance with VMS guidelines of the national Dutch road authority (Rijkswaterstaat, 2012), as can be seen in Fig. 2. This was done for comparability in terms of the amount of driver distraction. In the tenth drive – which included the embedded recall task – both the VMS as well as all electronic speed signs were blank for all participants.

2.4. Measures

To determine whether the critical route instruction on the VMS had been noticed, compliance behaviour in terms of taking the correct exit in drive 9 was measured. Driver comments regarding the critical route instruction were logged as well.

In addition to compliance, recall and recognition were also measured to assess whether the critical route instruction had been detected. Recall was measured both for the VMS text as well as for the electronic speed limits to prevent the VMS being singled out. It was measured in an embedded recall task as part of drive 10. Participants were instructed that all electronic road signs would be blank. Their task was to recall what these signs displayed in the previous drive, by verbally responding to a computer voice that questioned them while driving. The participants were questioned at each of the eight gantries and were encouraged to guess when uncertain about the answer. Per gantry, the computer voice either asked them which speed limit or – at the gantry equipped with the VMS – which message was displayed in the previous drive. To avoid confusion, for the latter the computer voice specifically referred to the large top sign instead of the speed sign. Additionally, before engaging in drive 10, participants were instructed to maintain the speed in accordance with the speed limit present in drive 9 during the whole drive. The recall and recognition question about the electronic speed limits served as control questions to ascertain ability to recall and recognise traffic-related information for both the control group and the advertisements group.

Recognition was measured in the final questionnaire succeeding all drives. Similar to recall – as for the same reason – the questions concerned all electronic road signs. For both sign types, it was suggested that there had been two groups who had received a dissimilar treatment. For the electronic speed limits, it was suggested that there had been one group for whom the speed limit on the gantries had always been 80 km/h and another group for whom the speed limit on the gantries had increased from 80 km/h to 100 km/h. For the VMS, it was said that for one group it had displayed that “the A31 to Bergdorp was closed due to an accident and that Oostdorp could be reached by following directions to Bergdorp”; while for the other group it had not. While in fact for both questions all participants belonged to the first group, they were asked to which group

they thought they belonged and how confident they were of their decision. Participants received feedback on both the recall and the recognition task only in the debriefing that finalised the experiment.

Expectations were assessed by asking what expectations one had held concerning possible variability in electronic road signs while driving, for both the electronic speed limits and the VMS. These questions were part of the final questionnaire and preceded the recognition questions. The questions concerning recall, recognition and expectations were based on the questionnaire and embedded recall task described in more detail by Harms and Brookhuis (2016).

To assess whether displaying the critical route information induced compensatory behaviour that would suggest increased attentional demands, driver speed was measured in the vicinity of the VMS and its nearest exit. For this, participant's speed, lane position, location and distance to the nearest exit succeeding the VMS were collected at a rate of 10 Hz. Erke et al. (2007) proposed that drivers who experience attentional overload due to a VMS text may compensate by lowering driving speed. Reducing speed lowers the amount of attention required to perform the task of driving, all other circumstances being equal (De Waard, 1996).

As an indication for habituation, drivers' speeds were measured. Rosenbloom, Perlman and Shahar (2007) established that drivers are more likely to speed in familiar locations, which is corroborated by repeated measures studies on the same road showing an increase of drivers' speed over trials (Charlton & Starkey, 2013; Harms & Brookhuis, 2016; Martens & Fox, 2007).

2.5. Data analysis method

The data sampling rate of the driving simulator was set at 10 Hz, which enabled the compilation of an average driving speed per decametre per participant per drive. For those who complied with the critical route instruction, average speed samples per decametre have been aggregated into average driving speeds per group to be able to compare speed between the advertisements and the control group and between specific road sections. For this analysis, paired samples T-tests were used.

The verbal responses to the embedded recall question concerning the VMS text were coded into one of seven categories; (1) reflecting the gist of the critical route instruction; (2) reflecting one of the commercial advertisements; (3) reflecting the road safety advertisement; (4) reflecting a combination of both types of advertisements; (5) VMS was blank; (6) participant cannot remember what the VMS displayed; or, (7) not reflecting one of the previous codes. For this, only the first given response was used; answers that were altered later on in the experiment were not taken into consideration. Two researchers coded all 32 entries with perfect agreement ($Kappa = 1.0$). When coding, both researchers were blind as to experimental condition. As the focus of this study is the behavioural response of taking the exit when exposed to the critical route instruction and, underlying this response, how this message was perceived, responses have been viewed as 'correct' when they reflected the gist of the critical route information rather than being word-for-word correct.

3. Results

3.1. Compliance: Taking the correct exit

The control group did not outperform the participants in the advertisements group in taking the correct exit. Results may even suggest the contrary. Seventy-five percent of the control group adhered to the detour message on the VMS. A binomial test showed that their compliance level did only differ from taking the exit by chance at a 10% significance level, $p = 0.077$. Whilst for the advertisements group, compliance with the critical route instruction was 81% which exceeded chance level (50%), $p = 0.021$. For comparing motorway exit behaviour between both groups a one-sided Fisher's Exact Test was used, as in both groups fewer than five participants failed to take the exit ($n = 4$ (25%) for the control group and $n = 3$ (19%) for the advertisements group). This test revealed that performance of both groups did not differ significantly, $p = 0.500$, and that effect size was low, $\Phi = 0.076$.

3.2. Recall and recognition

Of all participants, 63% of the control group and 56% of the advertisements group took the correct exit and passed for the subsequent recall and recognition tasks (see Fig. 3). This performance of the control group did not exceed that of the advertisements group, one-sided Fisher's Exact Test = 0.500.

However, participants' recall and recognition of the critical route instruction – measured in drive 10 and the final questionnaire, respectively – was not always in line with their behavioural response to it in drive 9. Fig. 3 shows that in the control group, every participant who managed to take the exit also correctly recalled the critical route information. In contrast, in the advertisements group, 31% ($n = 4$) failed to recall the critical route information they had previously adhered to (this equals 25% of the whole advertisements group, as shown in Fig. 3). Instead, all recalled one of the commercial advertisements. This recall performance differed from the control group (one-sided Fisher's Exact Test = 0.057) with large effect size, $\Phi = 0.419$.

When asked if they had been part of the group exposed to the critical route instruction on the VMS (the recognition question), all participants of the advertisements group who had taken the correct exit responded correctly. This, despite initial recall failures for part of these participants (on which they were not given any feedback until after the experiment). Of

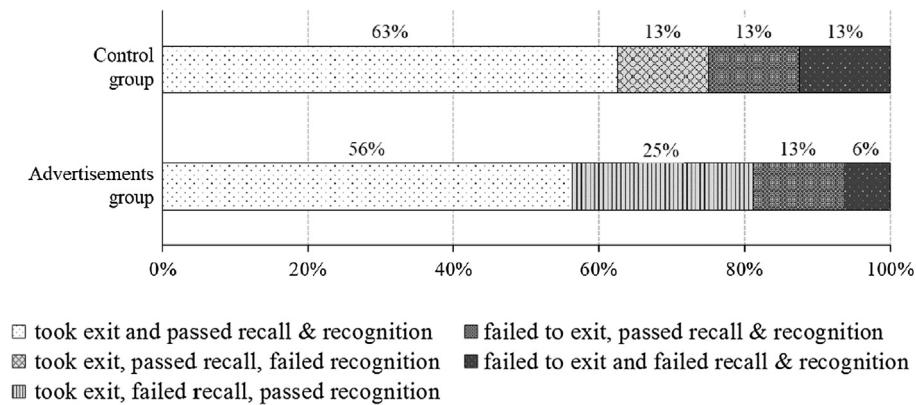


Fig. 3. Participants' response on the critical route information that had been on the VMS, per group.

the control group, 13% ($n = 2$) of those who had adhered to the critical route instruction failed the recognition question, as shown in Fig. 3. This recognition performance did not differ significantly from the advertisements group, one-sided Fisher's Exact Test = 0.220.

Of the participants who failed to take the correct exit, some did pass both the recall and the recognition task. This concerned an equal amount of participants in the control and the advertisements groups (13%, $n = 2$, per group). After passing the VMS in drive 9 some commented "did I see that correctly, should I take this exit?" and "the road wasn't closed at all!". This corroborates the suggestion that these participants saw at least part of the critical route information though they failed to act upon it. Furthermore, Fig. 3 shows that the remaining participants who failed to take the exit also failed the recall and recognition task: 13% of the control group ($n = 2$) and 6% of the advertisements group ($n = 1$). All indicated they were completely clueless concerning what had been on the VMS, if anything, or to have seen one of the three advertisements (comments from the control group and the advertisements group, respectively).

The control group and the advertisements group were equally able to both recall as well as recognise the fixed electronic speed limits they had encountered in all drives preceding drive 10. Performance was 100% accurate for both tasks, and for both groups.

3.3. Expectations

Based on their experience in drives 1 to 8, all participants in the advertisements group came to expect that the messages on the VMS could change. This is statistically significantly higher compared to the control group, one-sided Fisher's Exact Test = 0.022, with a large effect size, $\Phi = 0.430$. In the control group, 69% expected it could change. Moreover, one participant in the control group volunteered to report not having noticed the VMS until it displayed the critical route information in drive 9. Another remarked not having noticed the VMSs at all.

3.4. Compensatory speed behaviour

As shown in Fig. 4, both participants from the control group as well as the advertisements group displayed a dip in their speed behaviour when approaching the VMS. Hence, paired samples T-tests were performed comparing drivers' speed at consecutive locations near the VMS. The results are displayed in Table 2. It shows that for the control group, the dip – caused by a significant speed reduction in the 200–50 m preceding the VMS – was more pronounced compared to the advertisements group.

All drivers who took the exit ($n = 25$) or who missed the exit but passed both the VMS recall and recognition task ($n = 4$) displayed a dip in their speed behaviour preceding the VMS (see Fig. 5). Those who failed to take the exit but passed both the VMS recall and recognition task have been labelled as "aware of missing the exit". Drivers who failed to exit and failed the subsequent recall and recognition tasks ($n = 3$) have been labelled as "unaware of missing the exit". For them, the dip was non-existent; instead, they approached and passed the VMS in a constant pace. As only few participants ($n = 3$) failed to become aware of the critical route instruction and adhere to it, no further analyses were performed.

After passing the VMS, all drivers had at least 9.1–15.3 s before reaching the exit (based on the maximum and minimum average speed of all drivers, measured on this road segment).

3.5. Habituation

To assess habituation, driving speeds were compared over multiple drives. For this analysis the stretch of road from the start of the route to 1000 m before the VMS was used. This way, all stimuli were similar – and hence comparable – for drivers

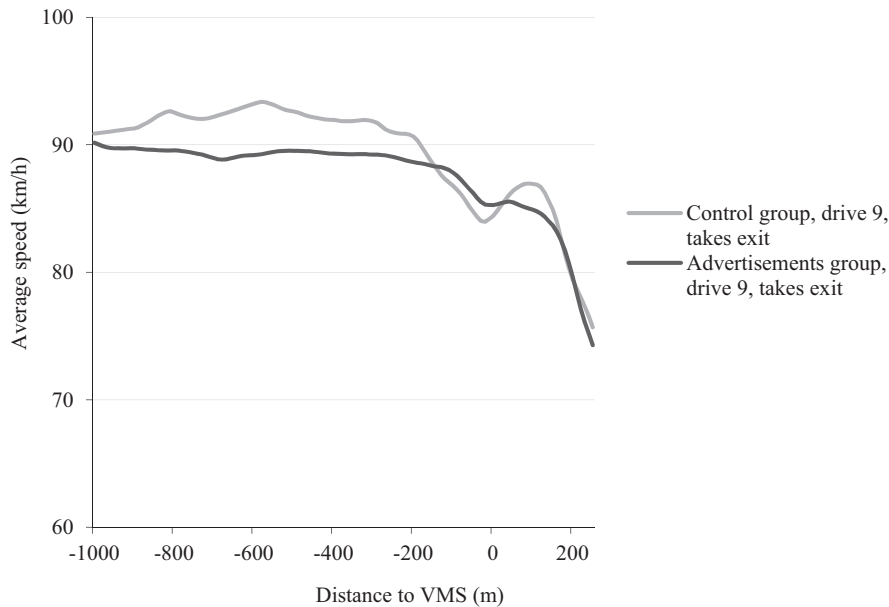


Fig. 4. Average driving speed in drive 9 near the VMS, exclusively for participants eventually taking the exit (differentiating between control group and advertisements group). The VMS displaying route information is the point of reference, hence differentiating between the distance before passing the VMS (–1000 to 0 m) and the distance between the VMS and the exit (0 to 273 m).

Table 2

Paired samples T-test comparing driver speeds at consecutive locations when approaching the VMS displaying the critical route instruction (drive 9). Distances to the VMS are displayed in meters before (–) or after (+) the VMS. Speed differences (speed dif.) represent the mean speed difference in km/h from one location to the next. This table shows that the control group decreased speed earlier and over a longer stretch of road compared to the advertisements group.

Distance to VMS	Control group				Advertisements group			
	speed dif.	t	df	sig	speed dif.	t	df	sig
–200 to –150	–1.74	3.14	15	0.007	–0.28	2.09	15	ns
–150 to –100	–1.62	4.13	15	0.001	–0.32	1.25	15	ns
–100 to –50	–1.89	2.84	15	0.012	–1.31	4.24	15	0.001
–50 to 0	–0.48	0.90	15	ns	–0.99	2.23	15	0.041
0 to 50	1.31	–2.05	15	ns	0.07	–0.19	15	ns
50 to 100	0.49	–0.77	15	ns	–0.25	0.48	15	ns

from the control group and the advertisements group. Furthermore, drive 1 and 10 were excluded as they consisted of the practice drive and the recall task. Average driving speeds per drive showed that both the control group as well as the advertisements group displayed a slow increase of driving speed after several drives (see Fig. 6). This pattern is confirmed by post hoc Bonferroni tests comparing average speeds in subsequent drives, displayed in Table 3.

4. Conclusion and discussion

Contrary to our expectations, this study provides evidence that displaying non-traffic related messages on VMSs (such as safety slogans and commercial advertisements) might not interfere with traffic management; provided the messages follow the format of a traffic management message in accordance with ergonomic VMS guidelines from e.g. Rijkswaterstaat (2012), as used in this study. It is likely that if ergonomic principles –such as refraining from using motion – are not met, the outcomes are less favourable. In addition, this study could not find prove that those repeatedly exposed to advertisements on the VMS showed signs of change blindness towards its critical route instruction (one of the main arguments of those opposing advertisements on VMSs). In fact, results indicate that the critical route instruction – informing drivers to take the nearest exit – resulted in compliant driver behaviour in the advertisements group. Whereas it did only moderately alter motorway exit behaviour for the control group.

The question is what may explain this behavioural difference. Examination of both groups shows they were similar in terms of background variables such as age and driving experience. With respect to cognitive performance, both groups were equally able to recall and recognise traffic-related information; both scored similarly well on recalling and recognising the electronic speed limits. Time to select and execute the appropriate compliant response after passing the VMS had been

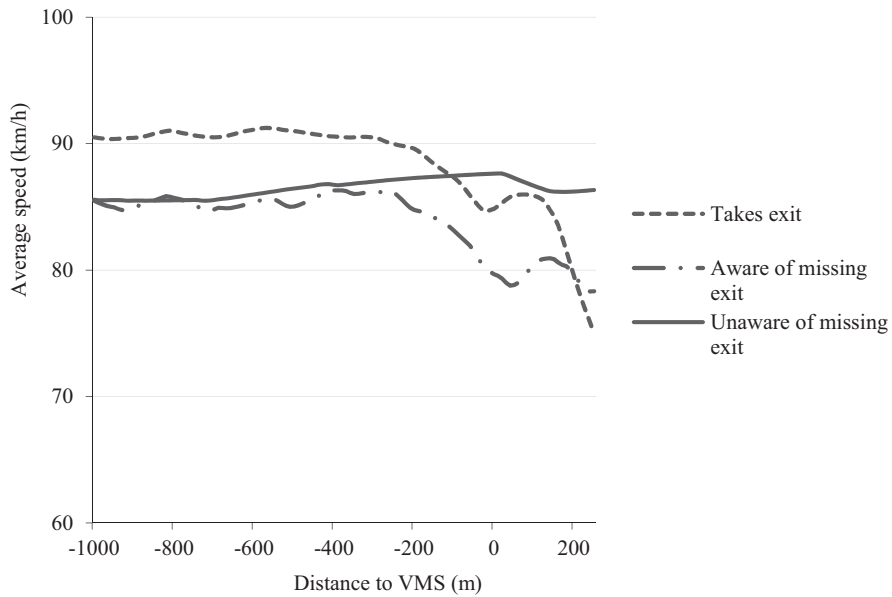


Fig. 5. Combined average driving speed of both the control group and the advertisements group in drive 9 near the VMS, differentiating between participants eventually taking the exit (n = 25), participants aware of missing the exit based on their knowledge of the VMS text (n = 4) and participants likely to be unaware of missing the exit based on their answers on the subsequent recall and recognition tasks (n = 3). Similarly to Fig. 4, the VMS displaying route information is the point of reference and is hence located at 'distance to VMS = 0'.

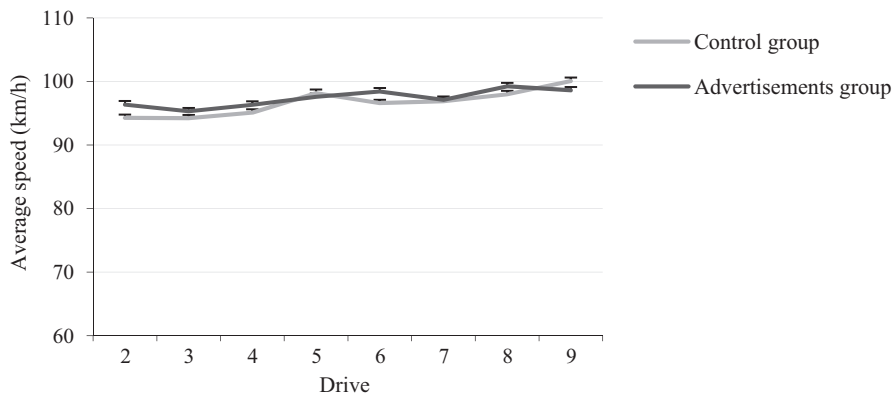


Fig. 6. Average speed per drive for the control group and the advertisements group, from the beginning of the route till 1000 m before the VMS. Note that till this point en route, driving circumstances were similar for participants of the control group and the advertisements group. Vertical lines represent 95% confidence intervals for mean. Drive 1 and 10 are excluded as they consisted of the practice drive and the recall task, respectively.

Table 3

Results for post hoc Bonferroni tests comparing average driving speeds per drive for both the control group and the advertisements group.

Drives compared	Control group		Advertisements group	
	95% Conf. interval (lower – upper bound)	Sig.	95% Conf. interval (lower – upper bound)	Sig.
2 and 3	-1.154 to 1.254	ns	-0.143 to 2.269	ns
3 and 4	-2.088 to 0.320	ns	-2.240 to 0.173	ns
4 and 5	-4.277 to -1.869	$p < 0.001$	-2.442 to -0.029	$p = 0.039$
5 and 6	0.380 to 2.788	$p = 0.001$	-2.051 to 0.361	ns
6 and 7	-1.498 to 0.910	ns	0.091 to 2.504	$p = 0.022$
7 and 8	-2.303 to 0.105	ns	-3.329 to -0.917	$p < 0.001$
8 and 9	-3.296 to -0.888	$p < 0.001$	-0.558 to 1.855	ns

sufficient for all; all drivers had at least 9.1–15.3 s before reaching the exit. In addition, the speed data over trials indicated that both groups showed signs of familiarisation with the drive (also a prerequisite to determine longer-term effects, e.g. based on expectations). Hence, the main difference between both groups is that the advertisements group had been repeatedly exposed to a variety of messages displayed on the VMS. In other words, the advertisements group received repeated practice with reading the sign. We believe that as a result of this repeated practice, drivers came to expect that the VMS texts could change (in contrast to the control group). Correctly expecting a message's presence reduces response time for it (Posner, 1980). This would explain why the dip in drivers' speeds preceding the VMS was nearly absent for the advertisements group. Speed dips for VMS texts such as seen in our control group have been recorded by Erke et al. (2007). Similar to Erke and colleagues, we interpret these speed reductions as compensatory behaviour to reduce attentional overload or distraction. This is corroborated by the finding that those who appeared oblivious of the critical route instruction (as they failed to adhere to it and failed to recall and recognise it) did not display compensatory speed behaviour when approaching the VMS. Following this interpretation, and analogous of De Waard (1996), this would suggest that the advertisements group needed less attention while still being capable of adhering to the information on display. This is also the case when tasks have been sufficiently well-practised and they have become skill-based (Rasmussen, 1983; Schneider & Shiffrin, 1977). Therefore we propose an additional explanation for both compliance with the VMS's instruction and the absence of a pronounced speed reduction when approaching it. We propose that due to repeated practice, drivers in the advertisements group may have accomplished reading the VMS text mostly at a procedural or automatic thus skill level. This would enable them to rely less on explicit consideration and process the information on display requiring little effortful conscious deliberation. Whereas for the control group, the sudden presence of a text displayed on the VMS caused control to shift from automatic to controlled, conscious processing.

Another surprising finding of this study is the fact that 31% ($n = 4$) of the advertisements group who complied with the critical route instruction subsequently failed to recall this message. This is a novel finding in traffic psychology research. To our knowledge, a similar result was only found in a study by Fisher (1992) on the recall of pictorial road signs and speed limits rather than written messages. Fisher found that 41% ($n = 11$) of drivers who reduced their speed after passing a pedestrian warning sign and subsequent speed limit sign, were unable to recall these signs only moments after passing them. Despite the lack of similarly strong research findings, there is other research pointing in the same direction. Harms and Brookhuis (2016) reported on a participant who complied with a sudden speed limit decrease without any recollection of the new speed limit (this one participant equalled 14% of those who adhered to the new speed limit). However, Harms and Brookhuis regarded this finding as an anomaly they could not explain. In a similar vein, Charlton (2007) found curve warning signs were quite effective for reducing drivers' speeds; while in a previous study Charlton (2006) he had found that many drivers fail to detect and recognise these signs. Recently these findings have been explained by proposing that conscious attention to roadside information "may not be required in order for drivers to process the information and react to it" (Charlton & Starkey, 2018). Instead, the information is processed at a subconscious, monitoring level for which little to no attention is required (Charlton & Starkey, 2013). Adherence to a critical route instruction while failing to recall it and lacking the necessity to strongly reduce speed to mentally process it, as found in the current study, support this theory. The proposed lack of conscious attention towards the critical route instruction also explains why in recall participants of the advertisements group experienced difficulties with retrieving the actual VMS text from memory and instead recalled what was usually on display (which was an advertisement). Contrary to recall, the recognition question may have served as a prompt, enabling participants to retrieve and confirm the actual VMS message (Tulving & Pearlstone, 1966). This might explain why despite recall failures, all participants in the advertisements group did pass the recognition test. In conclusion, this study shows that conscious attention might not be a prerequisite for compliance. As a result, recall of what was seen proves to be an inadequate proxy for assessing driver behaviour. Furthermore, it also leads us to believe that continuous variability in objects in the traffic environment can become part of the subconscious monitoring process, as long as they have been sufficiently practised.

Given the favourable behavioural effects found in this study, should road authorities deploy (commercial) advertisements on VMSs? The current study suggests that the main advantage of more frequently displaying information on VMSs is, that drivers become familiarised and experienced with reading these signs. Similar beneficiary effects were found by Jamson and Merat (2007), who used road safety slogans instead of commercial advertisements. Practice with reading VMSs might not so much involve the type of content of these signs, rather than the frequency and variability of this content. Hence, this study does not provide any justification that the content must involve (commercial) advertisements. It also does not provide evidence of the opposite and that it should not contain (commercial) advertisements. Further research on the type of content that is best provided to keep drivers well-practised is needed. One serious limitation of the commercial advertisements used in the current study is that they were explicitly designed not to exceed the level of driver distraction that is acceptable for traffic management messages and road safety slogans. This may contradict with the main aim of commercial advertisements, which is explicitly attracting attention. Another limitation of the research presented in this paper is the length of the familiarisation process. Although results indicated familiarisation, this process took 1.5 h instead of months or years. Controlling exposure to VMSs over a longer period is only feasible in a longitudinal field study. In conclusion, further research is required before road authorities should allow deployment of commercial advertisements on VMSs.

Acknowledgements

The authors would like to thank Connecting Mobility and Rijkswaterstaat – the national Dutch road authority –, and in particular Marja van Strien, for enabling this research. They would also like to thank all volunteer drivers who participated in this experiment; it would not have been possible without their effort. Finally, they wish to express their gratitude to the anonymous reviewers for providing helpful feedback that enabled the authors to further improve this paper.

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