MEASURING THE IMPACT OF DIGITAL INFORMATION DISPLAYS ON SPEED: A DRIVING SIMULATOR STUDY

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ABSTRACT

Speeding is a major problem in today's society and is estimated to contribute to about 30 percent of all fatal crashes. The primary objective of this study was to examine the impact of digital information displays on speeding behavior at 70km/h-to-50km/h transition zones. Two real world locations with a high percentage of speeding violations are rebuilt as realistically as possible in a driving simulator. Sixty-six participants completed an 18.9km trip within a randomized between (location: A, B) – within (condition: no display or one of three display messages: smiley, "You are speeding! / Thank you" or "Speed control") subjects design. The first two messages are social approval/disapproval messages, while the "Speed control" message confronts drivers with the (financial) risk of receiving a fine (i.e. a message more explicitly related to enforcement).

Results show a significant speed reduction effect of the three digital messages compared to the control condition from 50m before the digital display until 100m after the digital display. The largest mean deceleration was located between 50m and 25m before the digital display. The speed reduction effect of the "You are speeding / Thank you" and "Speed control" messages lasted until 175m after the digital display. Overall, the "Speed control" condition was found to be most effective (in terms of effect size as well as in terms of distance) in reducing speed. Finally, 500 meters after the devices no significant speed reduction was observed anymore. These results imply that a message more explicitly related to enforcement is more effective in reducing speed in speed transition zones compared to messages that socially disapprove speeding.

Keywords: traffic calming measures; digital displays; driving simulator; speeding

1 INTRODUCTION

Speeding is a major problem in today's society (*1,2,3*). Depending on the road type, 30 to 90 percent exceeds the posted speed limit (*2*). Several studies have revealed that approximately 30 percent of all fatal accidents can be attributed to speeding (*1,4*)). Explanations for speeding behavior can be found within three (interactional) domains: the driver, the traffic environment and the vehicle (*5*). Demographic characteristics, personality traits, external influences, attitudes and habits are known for the driver (*1,6*). Furthermore, road design and situational traffic conditions are important issues within the domain of traffic environment (7). Finally the current generation of vehicles (high maximum speed, comfort and power/weight ratio) makes it possible to achieve high speeds (*8*). Some drivers report feeling more comfortable when they drive at relatively high speeds, especially when they are rarely (or never) confronted with the negative outcomes of speeding behavior (9).

Speeding is a problem especially at 70km/h-to-50km/h transition zones (*2,10*). Dixon et al. (*10*) state that well defined transitional speed zones are necessary to encourage drivers to slow down gradually when they go from, for example, a higher speed rural road to a lower speed urban road. Roadway features and roadside conditions must help drivers to adjust their driving speed according to the road environment. In addition to others, Hallmark et al. (*11*), Dixon et al. (*10*) and the Federal Highway Administration (*12*) describe a variety of traffic calming treatments which can reduce the driving speed in rural/urban transition zones. Besides horizontal and vertical displacements, pavement markings, landscape treatments and digital information displays have the potential to reduce driving speed. In the sections below, we will focus on digital information displays.

1.1 Effectiveness of digital information displays

A digital information display (DID) is a radar activated sign that dynamically depicts oncoming vehicle speeds and/or messages on a large digital display (*11,13*). Studies conclude that these devices have a positive effect in reducing the driving speed and that they are especially effective in case of speeding drivers (*14,15,16*). DIDs can thus be used at problem locations (school zones, dangerous intersections, hazardous curves, work zones etc.) as part of a speed-control program (*14,16*).

Studies have found overall speed reductions of 2.3km/h up to 16.1km/h when a DID was installed (*13,17,18,19*). This speed reduction would lead to a significant reduction in injury collisions (6-9%) and fatal collisions (18%) at sites where a DID was operational. However, no lasting effect is observed once a DID is removed (*18,19*).

DIDs can also be very useful within freeway working zones. In situations where there was no treatment, the observed speed reduction was only four percent (*20*). The installation of a DID led to a further speed decrease of six percent. Police presence was most effective with a total reduction of 20 percent (*20*). Galizio et al. (*21*) concluded that speed reductions reflect an overreaction effect to the threat of punishment when a marked police vehicle was present. This suggests that driving speed is controlled more by external threat than by the value of safe driving.

In school zones, DIDs also tend to be effective in reducing driving speed (*14*). At DID locations in school zones, the average speed was reduced by about 8.2km/h (*22*). Casey and Lund (*23*) found that a DID was capable to reduce the proportion of vehicles exceeding the speed limit by at least 16km/h from 15 to 2 percent. However, this effect was only achieved during the time the DID was actually deployed. They also suggest that combined police enforcement is a crucial factor in DID effectiveness.

Although DIDs have tended to be effective in reducing speed, this effect was only found in the direct vicinity of the DID (i.e. no distance halo effect). In their field experiment, Walter and Broughton (*18*) found that the speed reducing effect was limited to 400m after the display.

Furthermore, Santiago-Chaparro et al (*15*) found that drivers started to increase their speed 90-150m after the speed feedback sign. This is similar to automated speed cameras where drivers sometimes reduce their speed when approaching the camera and then accelerate as soon as they have passed by (*24*).

1.2 Messages on digital information displays

Although the appearance of the message (i.e. static or flashing, color scheme etc.) is important (*25*,*26*), this study focuses more on the content of the message.

According to Van Houten et al. (*27*), posted feedback of speeding information is effective because of two reasons. First it introduces a social comparison factor (approval/disapproval) and second it is possible that the given feedback concerning speeding implies police surveillance (deterrence). Subjective norms (i.e. beliefs about whether a specific behavior will be reinforced or punished by others) play a key role in the approval/disapproval mechanism because drivers possibly will slow down as they believe that speeding is not appreciated by others (*27*,*28*). The deterrence mechanism is often used to achieve behavioral change: the behavior of an individual can be modified by inducing fear for the consequences of committing an illegal act (in this case: a traffic/speeding violation) (*3*,*29*,*30*). Deterrence is a concept where people react through fear for possible punishment in the short term. Here, the deterrent effect of a threat is higher when perceived certainty, severity and/or swiftness of punishment increase. In the long term, deterrence refers to the formation of habits and moral education which are based on the short term threats over time (*31*). Furthermore, the perceived (subjective) and actual (objective) risk of detection are two risk functions within a driver. The subjective risk is the result of the road user's perception of the intensity of enforcement and the objective risk reflects the actual level of enforcement (*3*,*32*,*33*). According to Riley (*32*), an optimal situation is achieved when the subjective risk equals (or exceeds) the objective risk.

A study conducted at work zones in Virginia (*16*) suggested that the following warning messages had a positive impact on high-speed drivers: "Excessive speed / Slow down", "High speed / Slow down", "Reduce speed / In work zone" and "You are speeding / Slow down". These messages were only displayed when a driver was speeding and they all generated significant speed reductions. Aforementioned messages are sometimes preferred over numerically represented speed because they tell the driver what action he or she should undertake (it is a strong command). Especially the last message is directly oriented to the speeders (*16*).

Wrapson et al. (*34*) performed a study in a 50km/h zone to measure the effect of a DID that consecutively depicted one of the following three messages:

- The average speed at the site: motorists may reduce their speed in order to comply with the behavior of the other road users
- A warning that the drivers' speed was being measured: drivers may reduce their speed in order to avoid possible fines
- A combination of both messages

These three messages had a positive impact on the observed driving speed. This suggests that both social comparison and the potential presence of police enforcement are mechanisms by which driver speed may be reduced (*34*,*35*).

The current study aims to investigate different types of DID messages: two messages are based on the approval/disapproval mechanism, while a third message makes a more explicit link to the presence of police control and thus, is related more to fear for punishment as a result of speeding.

2 OBJECTIVES

Since speeding is a problem in 70km/h-to-50km/h transition zones, the primary objective of this study is to examine the effectiveness of three DID messages on speed (*2*,*10*):

- Message 1: a DID with a laughing smiley when the driver's speed is below the speed limit (50km/h); otherwise a sad smiley (see FIGURE 1a)
- Message 2: a DID with the text "You are speeding!" when the driver is exceeding the speed limit; otherwise "Thank you" (see FIGURE 1b). Hereafter, this condition will be referred as "Too fast".
- Message 3: a DID with a warning sign "Speed control". This message is always displayed, thus independent of the current driver's speed (see FIGURE 1c).

These three messages are related to the deterrence mechanism. Message 1 and 2 are more based on the social approval/disapproval mechanism, while message 3 is more explicitly related to police enforcement and thus meant to induce fear for a speeding fine.

(a) (b) (c)

FIGURE 1 DID messages: (a) laughing and sad smiley, (b) "Thank you" or "You are speeding", (c) "Speed control"

Two real world locations with a high percentage of speeding violations and a comparable cross-sectional profile were selected from a registered police database. These locations are rebuilt in the driving simulator at the Hasselt University's Transportation Research Institute. At each location, the three types of DID messages and one control section (i.e. no implementation of a DID) were examined. We addressed the following research questions:

a. Does the presence of a DID (vs. control condition) have an effect on speed behavior?
b. Is there a difference in effectiveness among the digital messages?
c. How far does the effect of a DID extend in terms of distance (i.e. distance halo effect)? Concerning the distance halo effect, is there a difference between the digital messages?

Based on the literature, it is expected that a DID will reduce speeding. This leads to the following hypothesis: "a DID will reduce the driving speed in transition zones". Police departments may use these results to invest in more effective digital information displays for speed reduction.

3 METHODOLOGY

3.1 Participants

Eighty volunteers (all gave informed consent) participated in the study. Ten did not finish the experiment due to simulator sickness and four encountered a technical problem. No outliers were identified based on the three interquartile distance criteria. Thus, 66 participants (41 men), approximately equally divided over four age categories from 20 to 75 years old (mean age 45.2; SD age 17.0) remained in the sample. All participants had at least two years of driving experience. Age and gender were not taken into account as between-subject factors in the statistical analyses.

3.2 Driving simulator

The experiment was conducted on a medium-fidelity driving simulator (STISIM M400; Systems Technology Incorporated). It is a fixed-based (drivers do not get kinesthetic feedback) driving simulator with a force-feedback steering wheel, brake pedal, and accelerator. The simulation includes vehicle dynamics, visual/auditory (e.g. sound of traffic in the environment and of the participant's car) feedback and a performance measurement system. The visual virtual environment was presented on a large 180° field of view seamless curved screen, with rear view and side-view mirror images. Three projectors offer a resolution of 1024 × 768 pixels and a 60 Hz frame rate. Data were collected at the same frame rate.

3.3 Scenario

Road segment selection and description
The objective was to select two roads with similar percentages of speeding violations, comparable cross-sectional profiles and similar road surrounding environments. This selection was based on a data-driven approach and used the following variables: percentage of speed violations (i.e. the number of speed violations divided by the number of controlled vehicles), speed limit, number of lanes, number of curves and intersections, priority type, and presence of a median, cycle lanes, footpath, zebra crossings, parking lane and buildings. The speeding violations and speed limit data were extracted from an official police database and all the environmental variables were investigated through satellite images from Google Earth. The roads were first classified by their speeding violation rate, because roads with a high percentage are more problematic than roads with a low speeding percentage. To make a final decision, the most interesting (and comparable) locations were visited.

The two selected roads, with a violation rate of 22.5% and 18.8% respectively, each contain a 70km/h-to-50 km/h speed transition with 2x1 lanes, an adjacent cycling path and a roundabout in the 50km/h speed zone. At each location, three types of digital messages will be implemented in the driving simulator. More detailed information about the selected locations can be found below and in FIGURE 2.

Road segment development
To rebuild the selected locations in the driving simulator environment, a procedure called geo-specific database modeling (*36*) was adopted. This procedure consists of replicating a real-world driving environment in a simulated virtual environment and is to be differentiated from simulator research where often the driving scenarios are fictional. In order to reproduce the existing situations as realistic and detailed as possible, we made use of photographs, videos, detailed field measurements, AutoCAD drawings, and Google Street View. Pictures of the two real world 50km/h environments and their simulated replica can be found in FIGURE 2a and 2b.

Scenario design
The overall scenario is a systematic combination of the real life replicated sections (location A or B) with a set of 2km long filler pieces, differing from the analysis sections with respect to design, speed limit and surrounding environment and meant to provide some variation while driving. FIGURE 2c includes an overview of the scenario of the two selected locations with the corresponding speed limits.

Both analysis locations contain a transition from a rural to an urban environment and have a length of 3,100m. The DID is located at 170m (location A) or 575m (location B) after the 70km/h-to-50km/h transition. The DID is set at the relative distance of 0m (cf. FIGURE 2c). Because we are also interested in the distance halo effect of the DIDs, we included a replica of the real-world roundabouts and a 500m long road segment with a speed limit of 50km/h in the scenario. The roundabouts are located at respectively 450m (location A) and 370m (location B) after the DID. Note that the data-driven approach in the road segment selection and the geo-specific database modeling approach results in small differences – concerning the distance between the transition and the DID, the presence and length of the different speed zones and the location of the roundabout – between the two locations. The sample is divided into two groups: one group will drive in location A and the other group will pass location B. All participants are exposed to the four conditions: one control condition (no DID was implemented) and three DID messages.

Weather conditions were sunny and dry and random traffic was generated in the opposite direction. There was no traffic present in front of or following the driver in the participant's driving lane.

Procedure and design

Participants were asked for their voluntary cooperation and requested to fill out a form with some personal data (e.g. date of birth, driving experience, gender). After a general introduction, drivers acquainted themselves with the driving simulator by handling various traffic situations (e.g. urban and rural areas, highway, curves, roundabout, traffic lights) during two practice trips of 3 and 7km respectively. Then they completed the experimental trip of 18.9km at one of the two locations, resulting in a randomized between (two location: A, B) – within (four conditions: no display, smiley, "Too fast", "Speed control") subjects design. Subjects were asked to drive as they normally would in their own car and to apply the traffic laws as they would (or would not) do in reality. A GPS voice instructed them during the trip to follow the main road and go straight on at the roundabouts.

3.4 Data collection and analysis

Dependent measures

Driving performance measures for both longitudinal and lateral control were recorded by the simulator. For this study, measures for longitudinal control were of particular interest. Mean speed [km/h] is selected because it is used as an indicator for safe driving (*1*). Mean acceleration/deceleration (acc/dec) [m/s²] is interesting because fluctuations in acc/dec indicate (large) changes in speed and can cause discomfort. Sometimes it is difficult for drivers to anticipate safely these fluctuations, thereby increasing the chance of rear-end collisions (*37*).

Data analysis

Data analysis for mean speed and mean acc/dec is based on a number of measurement zones along the driving scenario. First, one random zone of 500m was analyzed (starting 1750m before the DID) to see whether significant differences exist among the four conditions. Under normal circumstances, no significant differences would occur because the DID do not have an influence at this distance. A randomized between (location: A, B) – within (condition: no display or one of the three digital messages: smiley, "Too fast" or "Speed control") subjects multivariate analyses of variance (MANOVA) was conducted on the two speed parameters.

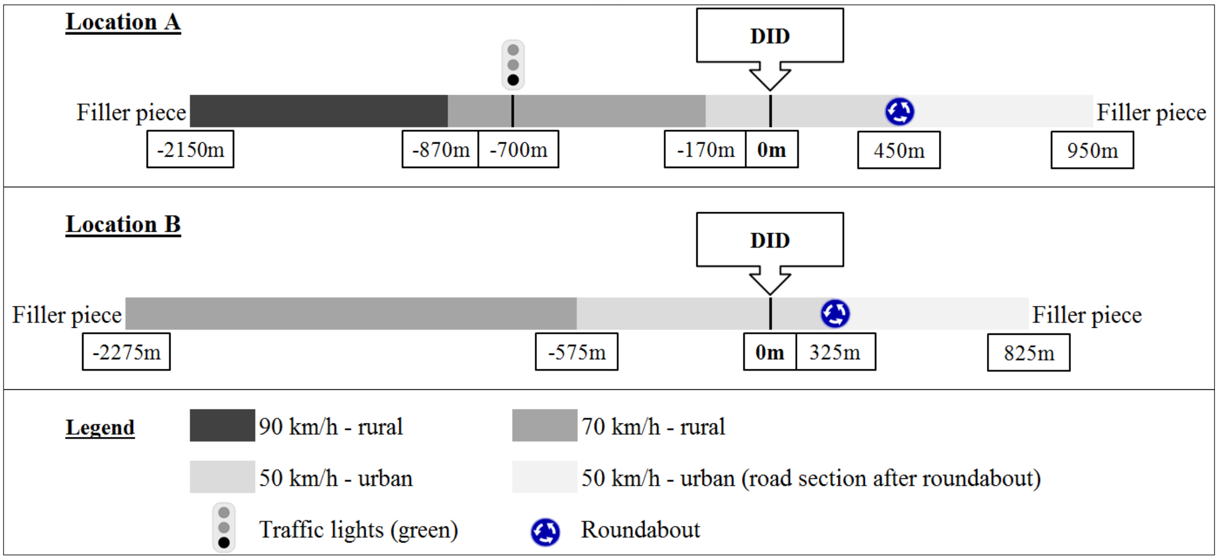
Since this study focuses on speed-related behavior (cf. research questions a and b) nearby the DID, six zones before and ten zones after the displays were analyzed. Each zone has a length of 25m, resulting in an analysis section of 400m (from -150m until 250m on FIGURE 2c). Therefore, a 2 (location) x 4 (condition) x 6 or 10 (zones of 25m) between-within subjects MANOVA was conducted on the two speed parameters: once for the six zones before the DID and once for the 10 zones after the DID.

To examine how far any effect of the DID endured in distance (cf. research question c), nine zones of 50m after the roundabout (see FIGURE 2c; 450m after the DID at location A; 325m after the DID at location B) were analyzed. Therefore, a 2 (location) x 4 (condition) x 9 (zones of 50m) between-within subjects MANOVA was conducted on the two speed parameters.

For all analyses, additional post-hoc univariate tests and ANOVA's were conducted and p-value was set at 0.05 to determine statistical significance. For MANOVA's F- and probability values (Wilks' Lambda) are reported. For univariate tests and ANOVA's, corrected F- and probability values (Greenhouse-Geisser) are described.

(a)

(b)



(c)

FIGURE 2 Real world vs. simulator images (a) at location A and (b) at location B; (c) Scenario overview

4 RESULTS

4.1 Control zone

The purpose of the control zone is to see whether significant differences exist between the conditions on a road section where the DID has no influence (i.e. 1750m before the DID). The MANOVA revealed that only Location is a significant factor ($F_{(2,63)} = 24.4$, $p < .0005$).

Subsidiary univariate analysis showed that mean speed at location A (M = 81.128, SD = 1.256) was higher than at location B (M = 71.342, SD = 1.219) ($F_{(1,64)} = 31.3$, $p < .0005$). Furthermore, the mean acc/dec was higher for location A ($F_{(1,64)} = 15.7$, $p < .0005$).

As was expected, no significant differences exist between the four display conditions in this control zone.

4.2 Immediate vicinity of digital information displays

TABLE 1 presents the multivariate and univariate statistics for the dependent measures for six zones of 25m before and ten zones of 25m after the DID (cf. research questions a and b). An overview of the results (for both locations together) can be found in FIGURE 3.

TABLE 1 Multivariate and univariate statistics for mean speed and mean acceleration/deceleration

	6 zones before		**10 zones after**	
Variable	*F (dfs)*	*p*	*F (dfs)*	*p*
MANOVA				
Location	2.0 (2, 63)	0.144	68.0 (2, 63)	**< .0005**
Condition	7.0 (6, 59)	**< .0005**	6.7 (6, 59)	**< .0005**
Condition x Location	1.1 (6, 59)	0.364	1.5 (6, 59)	0.188
Zone	4.8 (10, 55)	**< .0005**	10.2 (18, 47)	**< .0005**
Zone x Location	2.5 (10, 55)	**0.016**	11.1 (18, 47)	**<.0005**
Condition x Zone	2.6 (30, 35)	**0.003**	3.1 (54, 11)	**0.024**
Condition x Zone x Location	1.2 (30, 35)	0.298	1.9 (54, 11)	0.126
Univariate statistics				
Mean speed				
Location			28.2 (1, 64)	**< .0005**
Condition	1.3 (3, 179)	0.278	8.9 (3, 189)	**< .0005**
Zone	6.1 (2, 99)	**0.007**	69.8 (2, 113)	**< .0005**
Zone x Location	4.9 (2, 99)	**0.015**	57.2 (2, 113)	**< .0005**
Condition x Zone	6.1 (5, 295)	**< .0005**	3.5 (8, 490)	**0.001**
Mean acc/dec				
Location			133.4 (1, 64)	**< .0005**
Condition	10.2 (3, 179)	**< .0005**	5.0 (3, 173)	**0.003**
Zone	11.4 (2, 155)	**< .0005**	20.4 (4, 230)	**< .0005**
Zone x Location	8.1 (2, 155)	**< .0005**	23.2 (4, 230)	**< .0005**
Condition x Zone	2.3 (9, 559)	**0.014**	1.0 (12, 782)	0.433

p ≤ 0.05; *p ≤ 0.1*

For the **six zones before the DID**, the factors Condition, Zone, Zone x Location, and Condition x Zone are significant in the MANOVA. The significant interaction term Zone x Location indicates that longitudinal control in the six zones deviates between the two locations. Variations between the two locations in road environment and in location of the speed transition and the roundabout with respect to the DID (cf. FIGURE 2c) are the main causes for these differences. This interaction will not be discussed further in detail because this is not related to the research questions.

Subsidiary univariate statistics revealed that Condition x Zone is significant for both dependent measures. FIGURE 3a clearly shows that (irrespective of location A or B) the highest mean speeds are measured in the control condition. Between -150m and -50m no significant speed differences were found among the conditions. However, mean speed started to decrease from 50m before the DID in the conditions with digital messages compared to the control condition ([-50m; -25m]: $F_{(3,148)} = 3.4$, $p = 0.022$; [-25m; 0m]: $F_{(3,191)} = 10.1$, $p < .0005$).

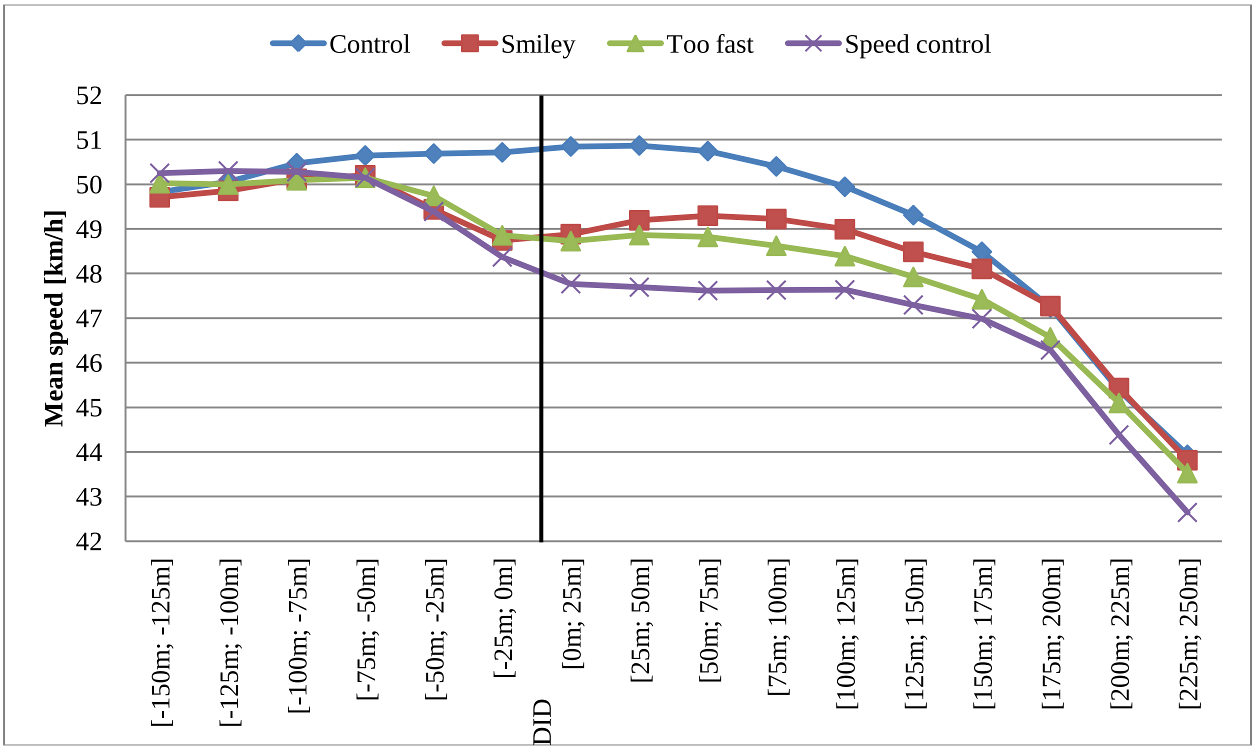
Post-hoc analysis for mean acc/dec shows that the largest deceleration in the conditions with DID occurs between -50m and -25m (cf. FIGURE 3b). This deceleration maneuver sustains during the last 25m before the DID with “Too fast” ($p = 0.003$) and “Speed control” ($p < .0005$). In addition, mean deceleration was significantly larger in the “Speed control” message compared to the smiley during these last 25m ($p = 0.001$).

Concerning the **ten zones after the DID**, the MANOVA revealed significant effects for Location, Condition, Zone, Zone x Location, and Condition x Zone (cf. TABLE 1).

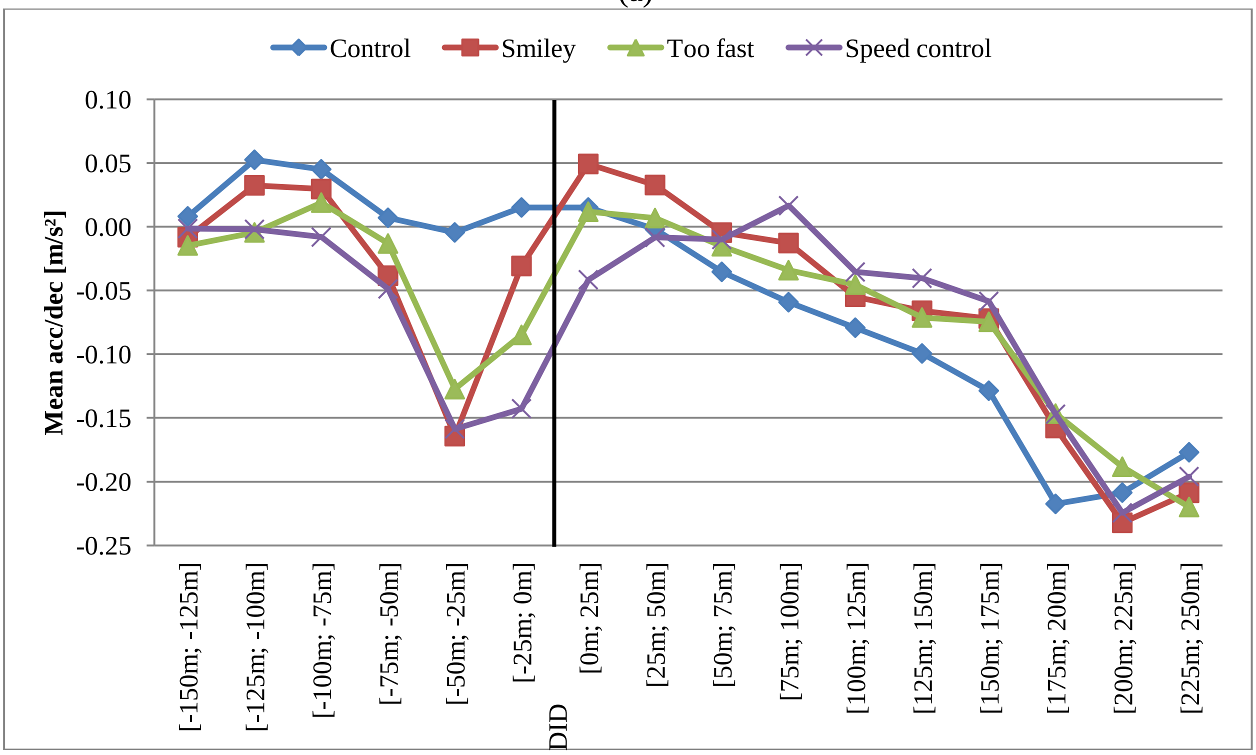
Additional tests for the interaction of Condition x Zone for mean speed show that during the first 100m after the DID, mean speed is significantly higher in the control condition compared to the three digital messages. During these 100m “Speed control” generated a lower speed compared to the smiley and ”Too fast”. From 100m after the DID, the speed reduction effect of the smiley disappeared. However, until 175m after the DID the messages “Too fast” and “Speed control” still have a positive effect. Both conditions generate a comparable lower mean speed than in the control condition and mean speed with the “Speed control” message was also lower than with the smiley. There was however no significant mean speed difference between the smiley and “Too fast”. Between 175m and 250m there were no longer any significant speed differences among the four conditions.

The significant main effect of Condition for mean acc/dec shows that during the 250m after the DID participants decelerated harder in the control condition.

To summarize, we found a significant speed reduction effect of the three digital messages compared to the control condition from 50m before the DID until 100m after the DID. The largest mean deceleration was also located between 50m and 25m before the DID. The speed reduction effect of the “Too fast” and “Speed control” messages lasted until 175m after the DID. Overall, the “Speed control” message was found to be most effective (both in terms of the extent of speed reduction as in terms of distance) in reducing speed.



(a)



(b)

FIGURE 3 (a) Mean speed and (b) mean acc/dec in the immediate vicinity of DID; irrespective of location A or B

4.3 Distance halo effect

To study the effect of a DID over a somewhat longer distance (cf. research question c), nine consecutive zones of 50m after the roundabout were considered. An overview of the results for this analysis zone can be found in FIGURE 4.The MANOVA revealed that only the factor Zone is significant ($F_{(16,49)} = 349.3$, $p < .0005$).

Subsidiary univariate tests show that mean speed ($F_{(3,173)} = 1073.4$, $p < .0005$) increased after the roundabout and stabilized close to the speed limit (50km/h) between 200m and 250m after the roundabout.

Concerning the distance halo effect, no significant differences were revealed between the conditions after the roundabouts (at 450m and 325m respectively).

The results for mean acc/dec ($F_{(4,261)} = 129.0$, $p < .0005$) show that participants accelerated after leaving the roundabout (with a peak between 50m and 100m after the roundabout) and that acceleration decreased to approximately zero at 250-300m after the roundabout, indicating that, from thereon participants maintained a rather constant speed.

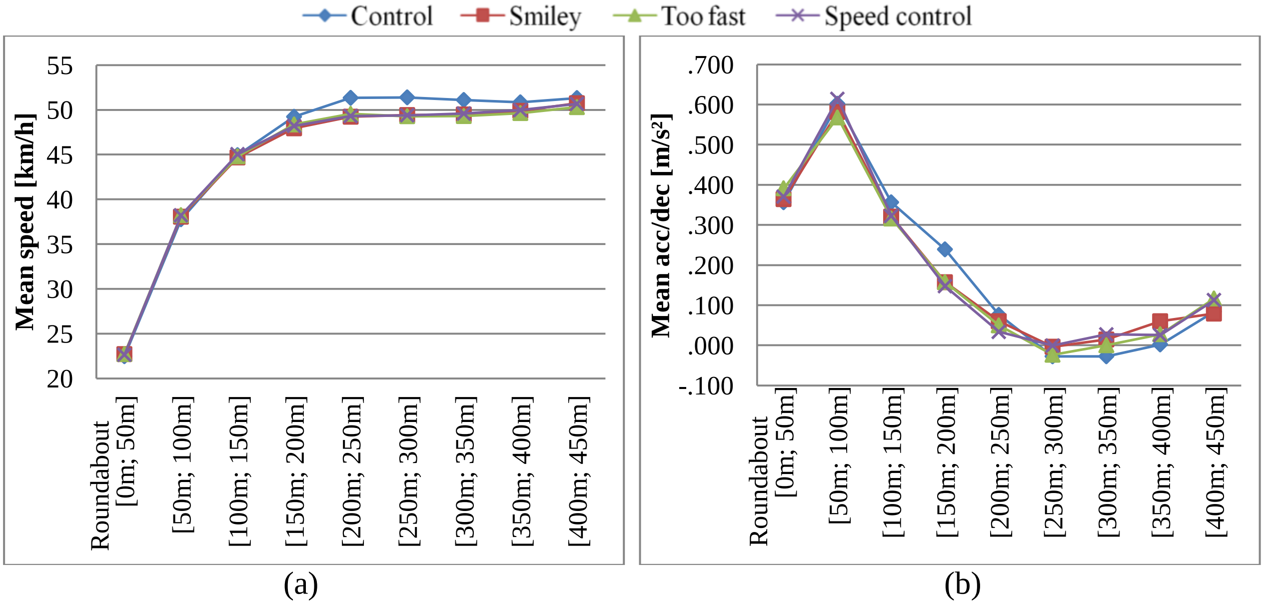


FIGURE 4 Distance halo effect for (a) mean speed and (b) mean acc/dec; irrespective of location A or B

5 DISCUSSION

In this study, two real-world road sections with a high percentage of speeding offences were selected and replicated in the driving simulator. Both locations had a comparable cross-sectional profile with a rural (70km/h) to urban (50km/h) road transition. At every location four conditions were implemented: no DID or one of the three digital messages: smiley, “You are speeding! / Thank you” or “Speed control”.

First, a control zone (500m long and started at 1750m before the DID) was analyzed. No significant difference was found among the four conditions, as was expected. However, the difference in speed limit at location A (90km/h) vs. location B (70km/h) resulted in a significant main effect of the factor Location.

The results for mean speed and mean acc/dec in the zones in the immediate vicinity of the DID and over a longer distance after the DID are discussed in sections 5.1 and 5.2 respectively.

5.1 Immediate vicinity of digital information displays

We found a significant speed reduction effect of the three digital messages compared to the control condition from 50m before the DID until 100m after the DID. The speed reduction effect of the "Too fast" and "Speed control" messages lasted until 175m after the DID. Overall, the "Speed control" message was found to be most effective (both in terms of size as in terms of distance) in reducing the speed.

The speed reductions (ranging from 1.2 to 3.2km/h) are comparable to those obtained in other (field) experiments where a DID was implemented. Other studies found a reduction of 8.2km/h (*22*), 5.3km/h (*17*), 6% (i.e. 3km/h when the average speed is equal to 50km/h) (*20*), 2.24km/h (*18*) and 0.8km/h (*38*) after a DID was installed. Studies about other traffic calming measures (e.g. transverse rumble strips) found comparable average speed reductions of 3.2km/h (*13*) and 5.9km/h (*39,40,41*). Since, in our study, the difference in messages did not play a role in the last 50m before the DID, the established speed reduction could be attributed to the mere presence of the device itself.

The fact that "Speed control" is more effective in reducing speed compared to the smiley and the "Too fast" message can possibly be explained in terms of the underlying message strategies: i.e. deterrence versus approval/disapproval. Galizio et al. (*21*) state that driving speed is controlled more by external threat (of receiving a fine) than by the value of safe driving. Maybe, a smiley through its rather suggestive and symbolic character is too 'soft' as an approach to stimulate drivers to lower their speed. Furthermore, Van Houten et al. (*27*) concluded that posted feedback of speeding information is effective because drivers think that this feedback implies police surveillance. With respect to the latter, several studies (*19,23*) found that DIDs in combination with police enforcement are a crucial factor to increase efficacy. To summarize, we can conclude that the creation of fear for a speeding fine is more effective in reducing speed compared to the approval/disapproval mechanism.

With respect to mean acc/dec, the strongest deceleration maneuver was established between 50m and 25m before the DID. The deceleration rate in this study is not higher than -0.25m/s² (cf. FIGURE 3b). This can be seen as a safe deceleration rate in light of deceleration values recommended by other studies: -0.85m/s² (*42*), -3.40m/s² (*42*) or -4.40m/s² (*43*). It is crucial that deceleration values are below these recommended values to obtain a safe traffic environment. Too high deceleration rates can lead to rear-end collisions and disturbances in traffic flow.

5.2 Distance halo effect

To see how long the speed reducing effect of the DID was maintained in terms of distance (cf. research question c), six zones of 50m following the roundabout (i.e. 450m after the DID at location A and 325m at location B) were analyzed. The results show that there is no significant difference among the four conditions. Therefore, we can conclude that the effect of digital messages is rather a local phenomenon.

This finding is in line with results from field experiments conducted by Santiago-Chapparro et al. (*15*) and Walter and Broughton (*18*) who found that the speed reduction effect of SIDs was limited to respectively about 90-150m and 400m after the speed feedback sign. Another conclusion was that no lasting effect was observed once the SID was removed (*18,23*). This local speed reduction effect has also been found in other studies concerning speed cameras (*44,45*). Furthermore, Ariën et al. (*46*) concluded that traffic calming measures (in this case: gate constructions) only reduced speed locally.

6 LIMITATIONS AND FUTURE RESEARCH

The issue of external validity often is raised when discussing the results of research employing driving simulations. Although the motivation as well as the experience of rewards and punishments of participants is hard to manage in a driving simulator (*47*),previous studies (*48,49*) have proven that DIDs can be examined in a driving simulator experiment. Furthermore, Bella (*50*) and Godley et al. (*51*) concluded that speed parameters can be relatively validated as dependent measures for research using a driving simulator. The geo-specific database modeling technique also increases reliability and validation of the experiment and the results (*36*). In addition, the simulator used in this study is equipped with a 180° field of view, which satisfies the prescribed minimum of 120° field of view for the correct estimation of longitudinal speed (*52*).

Future research about DID should be done concerning the time halo effect or the optimal location. Maybe different effects are found on other road types or roads with other speed limits. Finally, the duration of the effect in distance should be examined in more detail. In this study, no effect on driving behavior was measured anymore after the roundabout. Based on this experiment, it is not clear whether the distance passed after the DID or the passing of a roundabout (decelerating/accelerating) had an influence. A combination of both even might be possible.

7 CONCLUSION AND POLICY RECOMMENDATIONS

Considering the results for mean speed, DIDs can be considered as an interesting speed reducing measure. Already before the DID a speed reduction was observed compared to the control condition, which was possibly explained by the mere presence of the DID. The results show that the message “Speed control” was most effective in reducing the driving speed, followed by “Too fast” and the smiley. This implies that confronting drivers with the (financial) risk of receiving a fine is more effective in reducing speed compared to the social approval/disapproval messages. Police departments may use these results to invest in more effective digital information displays for speed reduction.

However, results have shown that this speed reduction effect was not preserved over distance. Already 325-450m (i.e. after the roundabout) after the DID, no significant differences were found anymore among the experimental conditions.

Considering the results of this study, the DID with the message “Speed control” can be recommended at locations with an important residential function that also have a speeding problem (e.g. school zones). The combination of a DID with other speed reduction measures would also be expected to increase its effectiveness. However, for maintaining the speed reduction effect and the credibility of these displays, police controls should be performed in the immediate vicinity at regular intervals.

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