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Warning sound to affect perceived speed in approaching roundabouts: experiments with a driving simulator

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Abstract

When examining facts concerning road safety, as stated by the United Nations General Assembly, one of the most important problems is vehicle speed.

The aim of this work is to evaluate the potential influence of traffic-calming measures on drivers' speed. In particular, attention focuses on warning sounds produced by communication between vehicles and infrastructures.

A driving simulator experiment was used to test the effectiveness of three speeding countermeasures, located along the approach to a roundabout in a rural area, together with the control condition (i.e., no countermeasures, corresponding to the current configuration of the roundabout): a continuous pitch playing throughout driving along the road segment and pitches activated by vehicle detectors at either constant or wide-to-thin (decreasing) distances.

Results showed that a continuous pitch is the most effective in reducing speed. Decreasing pitches still reduce speed to some extent, but constant spaced pitches only cause a small reduction in speed.

Since continuous beeping seems to be more effective immediately after it starts, but becomes less effective either after a given time interval or as the driver approaches the hazard, then the same effect found with this particular setting should still be found with shorter but continuous beeping. Using a shorter beep should, at least in theory, reduce any feeling of annoyance in drivers, as is the case with an extended pitch.

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1. Introduction

With resolution A/RES/64/255 of 10 May 2010, the United Nations (UN) General Assembly-proclaimed the period 2011–2020 as the “Decade of Action for Road Safety” worldwide: the aim was to reduce road traffic fatalities by increasing road safety-related interventions at national, regional and global levels.

According to the UN, one of the most important problems concerning road safety is excessive driving speed:

- an increase in average speed is directly related both to the likelihood of accidents and to the severity of their consequences;
- a 5% increase in average speed leads to an approximately 10% increase in accidents causing injuries to persons, and a 20% increase in fatal accidents (TRC, 2006);
- pedestrians have a 90% chance of surviving being hit by a vehicle traveling at 30 km/h or less, but less than a 50% chance of surviving impacts of 45 km/h or over [(TRC, 2006)];
- apart from reducing road traffic injuries and deaths, lowering the average traffic speed can have other positive effects on health outcomes (e.g., by reducing traffic pollution) (TRC, 2006).

These data unequivocally point to vehicle speed reduction as one of the most important ways of reducing the incidence of road accidents. For several years, the Transportation Laboratory of the Department of Civil, Architectural and Environmental Engineering, University of Padova, has been studying human behavior while driving. In particular, since 2010, a research program in collaboration with the Department of Developmental and Social Psychology has focused on road safety, by analysing drivers' behavior in simulated environments [(Rossi, Gastaldi & Gecchele, 2011); (Gastaldi & Rossi, 2011); (Rossi, Gastaldi, Gecchele & Meneguzzo, 2012); (Rossi, Gastaldi, Biondi & Mulatti, 2012); (Rossi, Gastaldi, Biondi & Mulatti, 2013)].

The aim of the present study is to evaluate the effect on drivers' maintained speed by a particular kind of traffic-calming measure: warning sounds (pitches) generated by communications between vehicles and infrastructures.

The paper is organized as follows. Section 2 gives a brief description of the technical literature concerning traffic-calming measures. Section 3 introduces the proposed system. Section 4 describes the methodology and experimental results. Concluding remarks and directions for further research are presented in Section 5.

2. Review of technical literature

In the last few decades, many researchers have focused on designing measures to reduce drivers' speed along road segments with potentially high rates of accidents [(Agent, 1980); (Daniels, Vanrie, Dreesen & Brijs, 2010); (Denton, 1980); (Drakopoulos & Vergou, 2003); (Jamson, Lai & Jamson, 2010)]. Most of these researches made use of tools like road markings to affect drivers' perceived and therefore maintained speed. In Denton's (1980) experiment, for instance, irregular transversal white bars were painted along a road section where the accident rate was exceptionally high because of drivers' excessive speeds; as the space between bars gradually decreased (i.e., the bars became more frequent), drivers were observed to reduce their speed; this measure is now applied in many countries. A similar study was conducted by Drakopoulos and Vergou (2003); other types of markings (e.g., chevrons) were painted on the surface of a real road, and significant reductions in drivers' speed were found (up to 24 km/h). Nevertheless, one of the main problems of these treatments is that their effectiveness wanes a few months after installation, a phenomenon usually explained as the “novelty effect” [(Denton, 1980; Martindale & Ulrich, 2010)]. That is, while approaching the treated road segment, drivers tend to reduce their speed because they see something they have never seen before on the surface of the road. After prolonged, repeated experience with this kind of stimulation, the feeling of novelty decreases and drivers consequently stop relying on the markings to adjust (i.e., reduce) their speed.

In a previous study, Rossi et al. (2013) applied the same rationale as Denton (1980) but examined various types of tools (e.g., guide posts) to induce drivers to slacken speed as they approach roundabouts. Guide posts,

unlike road markings, are commonly used to define the edge of the road and to help drivers by indicating the alignment of the road ahead. In this way, at least theoretically, guide posts (unlike markings) are not expected to elicit any feeling of novelty in drivers. The results obtained by Rossi et al. (2013) show that, with respect to constantly spaced guide posts and optical speed bars [see, (Montella, Aria, D'Ambrosio, Galante, Mauriello & Perneti, 2010)], wide-to-thin guide posts (i.e., the distance between posts slowly decreases as drivers approach a roundabout) produced larger and significant reductions in speed. As guide posts became nearer to each other (i.e., their spatial frequency increased), drivers tended to overestimate their speed and consequently slowed down as the roundabout came closer, a phenomenon commonly thought to be a consequence of the manipulation of such a specific optic flow [see, (Kemeny & Panerai, 2003)].

The above studies aimed at reducing drivers' speed by manipulating their perceptual representation of the road environment. Another way of inducing drivers to slacken speed while driving along potentially dangerous road segments is to consider other types of systems which, unlike perceptual measures which attempt "covertly" to affect drivers' speed, explicitly warn drivers by means of audible signals. So far, with the increase in the number of vehicle-based assistance technologies, few studies have tested the effectiveness of special Advanced Driving Assistance Systems (ADAS), which emit audible warning signals as soon as the maintained speed exceeds a certain limit (Adell, Varhelyi & Hjalmdahl, 2008; Young & Regan, 2007): this is currently a feature of some commercial GPS navigators. In the study of Adell et al. (2008), for instance, the authors installed what they called a BEEP system (a warning system emitting beeps and flashing red lights when the speed limit is exceeded) in a real vehicle; the effects of both BEEP and AAP (Active Accelerator Pedal - a system producing haptic feedback exerting a counterforce in the accelerator pedal at speeds over the limit) were tested in a field study. Results showed that both systems had positive effects by reducing drivers' maintained speed but, in general, the effects of AAP were larger and more significant across scenarios involving various speed limits than those produced by BEEP. More interestingly, when drivers were asked subjectively to evaluate their driving experience, BEEP was considered "annoying" or "irritating" but, at the same time, it "raised more alertness" than AAP.

In the present study, a new ADAS was tested. Auditory signals were presented to drivers not continually, but only while they were driving along dangerous road segments in which the likelihood of being involved in an accident due to high speed was greater. Unlike perceptual measures, the tested ADAS aims "overtly" to warn drivers by emitting beeps.

In a way, the system proposed here represents a translation from a visual to an auditory plan of the measures proposed in (Rossi et al., 2013).

Starting from the consideration that driving simulators can provide reliable observations of drivers' behavior [(Bella, 2005); (Bella, 2008); (Kaptein, Theeuwes & van der Horst, 1996); , Triggs & Fildes, 2002); (Bittner, Simsek, Levison & Campbell, 2002); (Rossi, Gastaldi, Meneguzzer & Gecchele, 2011); (Klee, Bauer, Radwan & Al-Deek, 1999)], a driving simulator was used to achieve the experimental control required to examine the effects of the analysed measures on drivers' speed.

3. Proposed system

The proposed system could be implemented as an ADAS. It is based on a simple idea: pitches are produced inside the vehicle when the vehicle moves along a road section (activation section). The signal representing the input for the system may come from a roadside source (e.g., a Bluetooth antenna) or from the position of the vehicle on the road (e.g., GPS data). Considering a critical road segment, a series of activation sections were arranged at a certain distance (constant or variable) from each other. In the case of constant distance, when vehicles are driven at increasing speeds, a series of pitches characterized by an increasing time frequency is obtained. This phenomenon is expected to affect drivers' perception of speed and therefore to induce them to

slacken speed. Manipulating the distance between activation sections along the road segment can lead to various effects on drivers' speed regulation.

4. Proposed approach

The experiment took place at the Transportation Laboratory, where the driving simulator is located.

4.1. Apparatus

The simulation system used is a fixed-base driving simulator produced by STSoftware® (Figure 1). It includes:

- a realistic functional cabin: seat with seat belt, steering wheel, pedals, gear lever, indicators, handbrake, ignition key
- three networked computers
- 5 full HD screens: images of the environment and virtual dashboard of car
- surround sound effects



Fig. 1. Driving simulator at University of Padova Transportation Laboratory

4.2. Participants

The sample of participants was composed of 27 drivers, 8 women and 19 men. Drivers were students, University staff or others having the following characteristics:

- absence of previous experience with driving simulators;
- at least 1 year of real driving experience;
- average annual driven distance of at least 1,500 km.

A summary of test drivers' characteristics is given in Table 1.

Table 1. Test drivers' characteristics: age and driving experience

	Mean	Standard Deviation	Range
Age	26.18	3.25	22-39
Years of driving	7.74	3.3	3-21
Km driven per year	11,370	8,584	1,500-40,000

4.3. Virtual scenario

During the experiment, participants drove along a circuit 8.73 km long (Figure 2a) composed of eight 1.1-km straight stretches connected by seven roundabouts, all having the same geometric features (Figure 2b) and corresponding to a real-life roundabout in the rural road network near Venice, Italy.

In this work, the effects of three countermeasures were compared with one control condition (i.e., no countermeasures):

- activation sections were placed at a constant distance of 20 meters;
- activation sections were placed at wide-to-thin (decreasing) distances, ranging from 20 to 5 meters;
- a continuous pitch was played throughout the treatment segment.

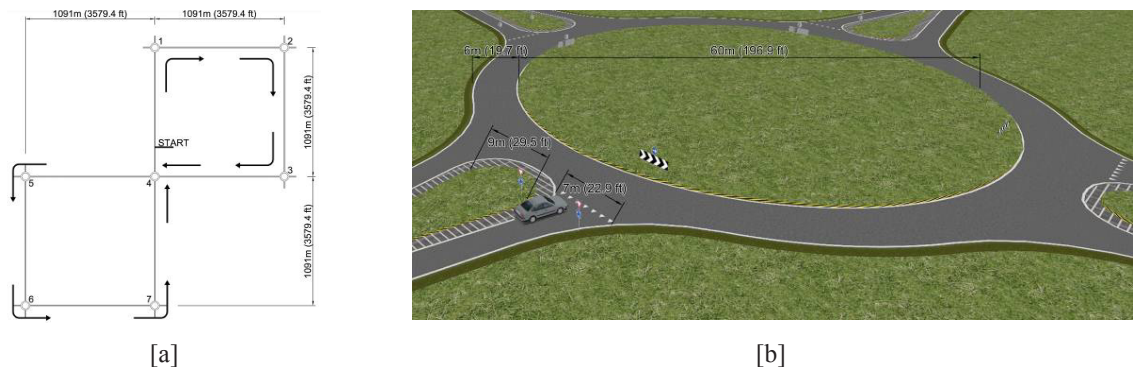


Fig. 2. Circuit map [a]; roundabout configuration and geometric features [b]

A set of 27 circuits was designed and developed. Each circuit represented a randomly extracted sequence of the three treatments and the control condition. Each of these was placed twice along the circuit

(treatments/lap=2). The treatment segment was placed on the approach lane, 200 meters from the point of entry to the roundabout. Five observation points were identified (Figure 3) as references to measure vehicle speed.

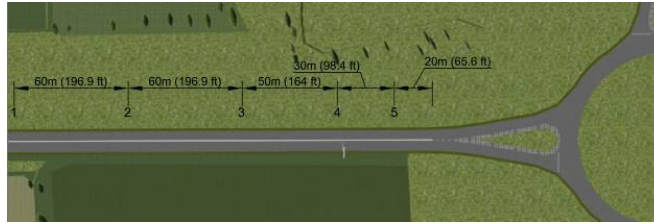


Fig. 3. Treatment segment and points of speed observation

4.4. Tasks

Each driver was asked to complete 5 laps along the circuit (randomly sampled from the 27 available without replacements), approaching 8 roundabouts. As a consequence, each treatment was presented ten times to each participant (laps x treatments/lap = 5 x 2 = 10).

Participants were asked to drive as they would normally do in the real world; the speed limit was 90 km/h. At each roundabout, drivers were informed about the direction to take by both vocal instructions and a head-up display (HUD); in this way, they always followed a predetermined path (Figure 2a). Traffic was present in the opposite lane, although the drivers were not constrained by any vehicles in front of them. It should be noted that the drivers were not informed about the meaning of the pitches.

The experimental session was preceded by a 15-minute practice session, in which participants familiarized themselves with the simulation by driving in an acclimatization scenario.

Daytime and good weather conditions were adopted in both experimental and practice scenarios, to ensure good visibility.

4.5. Data processing and analysis

Data were standardized in order to keep entry speed constant for each participant within each condition: mean speed measured at point 1 was subtracted from mean speeds measured at subsequent points (i.e., 2 to 5). In particular, points 1 to 5 were located at 220, 160, 110, 80, and 50 m, respectively, from the roundabout.

Table 2. Mean speed reductions in km/h (M) and standard errors (SE) at each measurement point

Treatment	Measurement Points (distance from roundabout)							
	2(160m)		3(110m)		4(80m)		5 (50m)	
	M	SE	M	SE	M	SE	M	SE
Control	-6.82	0.66	-19.19	1.28	-31.13	1.70	-41.75	2.13
Constant	-9.03	0.79	-20.75	1.55	-31.68	1.95	-41.8	2.24
Decreasing	-8.49	0.75	-20.83	1.43	-32.11	1.83	-42.71	2.20
Continuous	-9.82	0.88	-21.88	1.58	-33.08	2.11	-42.72	2.49

A repeated measures Analysis of Variance (ANOVA) with Treatments (4 levels: control, constants, decreasing and continuous pitches) and Measurement Points (4 levels: points 2-5) on standardized data revealed the

significant main effect of both Treatments ($F_{3,78}=3.6$, $p<.05$, partial $\eta^2=.12$) and Measurement Points ($F_{3,78}=331.2$, $p<.001$, partial $\eta^2=.93$). The interaction between them was not significant ($F_{9,234}=2.5$, $p=0.59$, partial $\eta^2=.08$).

Results (Table 2) were further inspected by comparing the levels of each factor with the Bonferroni correction. This correction, one of the most conservative, is of multiple-comparison type and is used when several dependent statistical tests are performed simultaneously, to reduce the likelihood of rejecting the null hypothesis when it is true (type 1 error). In practice, the alpha value (0.05) is adjusted according to the number of comparisons performed [see (Shaffer, 1995)]. All levels of Measurement Points significantly differed from each other ($p<.001$); in particular, the paired comparisons of point 2 vs. point 3, 3 vs. 4, and 4 vs. 5 all proved to be significant ($p<.001$). This suggests that drivers reduced their speed as they approached the roundabout, regardless of the treatment. With respect to the factor Treatment, multiple comparisons revealed that Treatment 4 (continuous beeping), but neither Treatment 2 nor Treatment 3, significantly differed from the control condition ($p<.05$). Since continuous beeping represented the only condition significantly different from the control condition, we tested for the effect of this manipulation at all Measurement Points: the effect of continued beep significantly interacted with the measurement points ($F_{3,78}=4.2$, $p<.05$, partial $\eta^2=.14$). Again, when adjusted with the Bonferroni correction, pair-wise comparisons on the Measurement Point levels were significant with respect to each other ($p<.001$). The data are plotted in Figure 4.

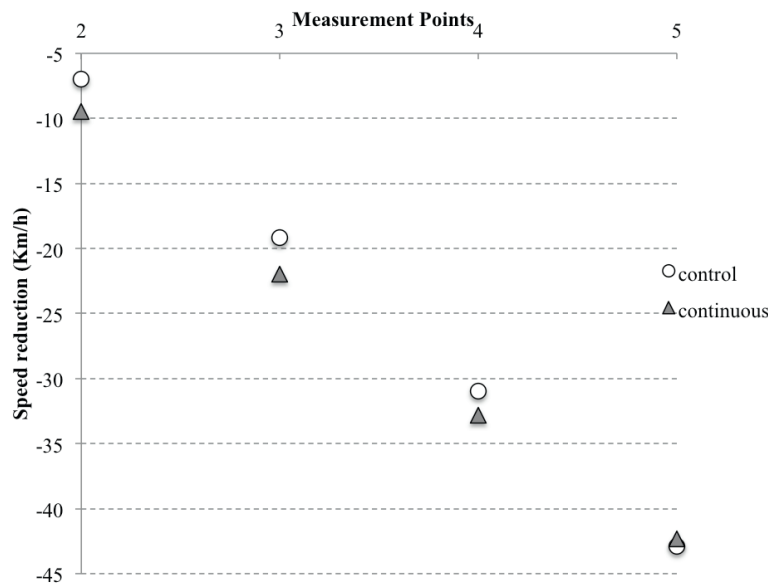


Fig. 4. Standardized speed reductions in km/h at five measurement points.

5. Summary and Conclusions

The potential impact produced on speed by traffic-calming measures was evaluated in this work. In particular, the effectiveness of reducing speed in three different treatments: constant, decreasing and continuous pitches was examined. Unlike other researches in which ADAS were activated as soon as drivers' speed exceeded certain

limits, in this case, activation, as designed and tested here, closely depended on the level of danger associated with a particular road segment: if the danger of being involved in a car accident along a given road segment due to speeding is high, the system is activated, otherwise it is not. In the study by Adell et al. (2008), participants described beeping systems as annoying or irritating. Similar results were obtained by Dijksterhuis, Stuijver, Mulder, Brookhuis & de Waard (2012) in their study on an ADAS system warning drivers as soon as their position within the lane became unsafe by means of an HUD. Interestingly, when asked to report their subjective driving experience, 39% of participants stated that they ignored the HUD. These data, obtained in two different studies testing different ADAS systems, indicate that assistance systems do not always assist drivers, but may in fact sometimes produce negative effects on drivers' attention and, generally, on their driving and safety. One possible explanation is that ADAS, when emitting signals frequently and for relatively long periods, may become a potential source of disturbance for drivers.

One of the aims of the proposed ADAS was to attempt to reduce the disruptive impact of beeping on driving. Of the three treatments considered here, the one producing a significant reduction in speed was that emitting continuous beeping. In particular, significant slowing of up to 3.3% with a speed limit of 90 km/h was found, a reduction largely falling within the range of 2-4% commonly found in these kinds of studies (see, e.g., Jamson et al., 2010). Interestingly, although participants, as expected, tended to reduce their speed as they approached the roundabout, regardless of treatment, such a significant effect on speed produced by that treatment still remained significant even when drivers were only 20 m from the point of entry to the roundabout. It should be noted that, at that distance, drivers' average speed was about 55 km/h in the control condition: this means that the reduction in speed produced by continuous beeping at that distance from the hazard (1.9%) is still consistent with existing literature, as well as significant in reducing the risk of accidents.

Another interesting result was the significant interaction found when controls and continuous beeping were analysed as the two levels of Treatment: as drivers approached the roundabout, the effect of continuous beeping in reducing speed lessened (from 3 to 1 km/h, according to the standardized differences in Table 1). This fact has two different implications. First, continuous beeping is not only effective in reducing speed, but also seems to produce smoother braking by drivers, with respect to controls. Second, since continuous beeping seems to be most effective immediately after it begins but then lessens either after a given time interval or as the hazard becomes closer, then the same effect found with this particular setting should still be found with shorter although still continuous beeping. At least in theory, using shorter beeping should reduce any feeling of annoyance produced in drivers by an extended pitch.

Nonetheless, our study contains two important limitations. The first concerns the absence of subjective measures. Unlike the studies cited above, in our experiment participants were not asked to report their subjective feelings about their driving during the experiment. Thus, we cannot ascertain whether the presence of ADAS disturbed them or not; the only thing we can be sure about is that the effect of continuous beeping on speed remained even after almost an hour and a half of experimentation. The second limitation concerns the warning effect in itself. In the psychophysiological and experimental psychological literature, warning pitches such as beeps are commonly used to trigger the so-called "startle response/reflex" [see, (Lipp, Siddle & Dall, 2000)]. This is an involuntary muscular reaction to sudden unexpected stimuli such as pitches. This response, if triggered by our beeping system, may have had detrimental effects on driving, because it could potentially cause drivers to lose control of their vehicle for a short period of time. One way of identifying the presence of such a reaction in response to ADAS beeps while driving would be to examine steering wheel and accelerator pedal movements, besides the Skin Conductance Response (Lipp et al., 2000). If such a response is actually triggered, then a certain amount of variability in steering radius and pedal pressure respectively should be observed, at least within the time interval following the first beep.

In conclusion, our experiment designed and successfully tested a new ADAS, helpful in reducing speed along road segments in which the danger of being involved in a car accident due to speed is high. Unlike other systems currently installed in vehicles, our ADAS is potentially less disturbing for drivers, since it warns them less

frequently than other systems such as those quoted above and, more importantly, only does so along highly dangerous road segments. To control for potential detrimental effects and to test the system in a real driving scenario are two possible aspects of research to be examined in future.

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