Additional road markings as an indication of speed limits: results of a field experiment and a driving simulator study

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1 Introduction

According to the regional road safety policy, speed limits on a considerable number of roads in Flanders-Belgium were reduced since 2002 from 90 to 70 km/h. As the measure was not of a general nature, all speed restrictions on the targeted roads had legally to be indicated by appropriate signs according to the highway code, i.e. mainly through an indication of the 70 km/h speed limit by a C43-sign (figure 1) beyond each intersection .

Except from the speed limit change, no other specific measures were taken on the targeted roads. In 2005, mean speeds on 70 km/h roads in Belgium were 75 km/h whereas the 85 percentile speed amounted to 86 km/h. In comparison with other speed limits, the 70 km/h roads were the class where the difference between the V_{85} and the legal speed limit was the highest (FCVV, 2007). At the same time, not complying to speed rules is believed to be one of the most important reasons for road accidents (MVG, 2008). Therefore, the need was felt for supplementary speed reducing measures, particularly on the 70 km/h-roads. In the long run it is aimed to design roads according to the 'self-explaining roads'-principle, meaning that roads should be designed in such a way as to spontaneously elicit the optimal behaviour, in particular the speed behaviour, as intended by the system owner (Theeuwes and Godthelp, 1995). However, in the shorter run the road authority strived to implement a more cost-effective road design system that was generally applicable and enabled the benevolent road user to comply to present rules. The Roads and Traffic Agency decided therefore to set up an experiment with a specific type of road marking that would serve as an additional and permanently available informative element for road users on 70 km/h roads. The implicit rationale behind this was that drivers who are better informed about the prevailing speed limit comply better to speed rules, clearly meaning in this case that mean speeds should decrease.
Two different types of additional road markings were developed, both fitting in existing national legislation and being in line with the European Agreement on Road Markings (UNECE, 1957). The first type was a white 0.5 m long line marking painted on the right side of the roadway, close to the existing continuous edge line in longitudinal direction and repeated every 50 m (figure 2). The second type was a white number '7', like the first type marked close to the edge line and repeated every 50 m. Both types are in the remainder of this paper referred to as respectively the Line and Number markings. It is worthwile to mention that some alternatives for the investigated markings were considered, e.g. replacing the existing continuous edgeline by an interrupted line, but this appeared not to be compatible with the European Agreement on Road Markings.
The project was evaluated in two ways. The first evaluation consisted of a field experiment on four road segments. The second evaluation was done through a driving simulator study. Since the direct target effect of the measure was

Figure 1: C43 speed limit sign

to affect speed behaviour, mean/median speeds were chosen as measurement variable in both evaluations. Sections 2 and 3 describe method, data and results of the field study and the simulator study respectively. In section 4 the results of both studies are compared and discussed. Finally some conclusions are drawn in section 5.

2 Field experiment

The field experiment was set up to evaluate the two types of additional road markings on four roads. Its main goal was to measure the effects on median speeds under realistic traffic circumstances. The experimental design was elaborated jointly by the researchers and the road authority, after the latter had decided upon the geometry of the experimental road markings and the location of the experimental roads. Two conditions, one with and one without supplementary information to drivers, were tested.

2.1 Design

Four 70 km/h road segments in four different provinces were selected as experimental roads (table 1). The Line markings and the Number markings were drawn, each on two segments. A few weeks after the drawing of the markings an information panel was placed to explain the meaning of the markings (figure 2).
The Roads and Infrastructure Agency collected speed and traffic volume data on the four experimental roads. The same data were collected on four comparison roads during several weeks. One comparison road was selected in each province, resulting in one comparison road per experimental road. The comparison roads were, except from the absence of the intervention, comparable to the experimental roads and had the same 70 km/h limit. All comparison roads had to be at least 20 km away from the experimental locations. The markings were drawn on different dates during May 2006. Collection of the speed data started one week before the marking and lasted at least one week per measurement period. The measurement periods for the experimental roads and the comparison roads per province matched to each other.
The information panel was erected on average three weeks after drawing the markings. After measurements were held on three moments: the first after drawing the markings (period 1), the second immediately after erecting the information panel (period 2a) and the third four months later (period 2b). Figure 3 shows the sequence of the treatments and measurements.

Province	Marking	Road nr.	Marking date	Inform. panel
Antwerp	Lines	N133	1 May/06	23 May/06
Flemish Brabant	Lines	N28	9 May/06	23 May/06
East Flanders	Numbers	N9	16 May/06	20 Jun/06
West Flanders	Numbers	N50	9 May/06	31 May/06

Table 1: Experimental roads

Figure 2: Line markings and information panel

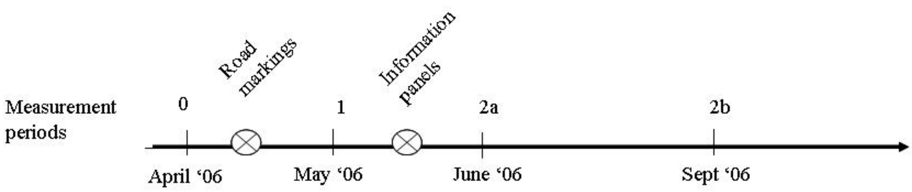

Figure 3: Timeframe treatments and measurements

2.2 Method

The software aggregated the speed data to median speeds on either a 15 min or an hourly basis, depending on the measurement equipment. Individual vehicle speed data were therefore not available which meant also that no information was available about the variance of the data. For both experimental and comparison roads, speed measurements on one location per province in both driving directions were available. An a priori promising analysis technique was an ARIMA-time series analysis, allowing to account for serial correlation in the data and periodic fluctuations. However, the data needs for such a technique did not appear to be fulfilled since the available data were not continuously measured, but in four separate time blocks before and after the drawing of the marking and the installation of the information panel. A different strategy was therefore adopted. Evolutions were calculated for five combinations of before- and after-periods (see figure 3): 0-1, 0-2a, 1-2a, 0-2b and 1-2b. For each of the experimental locations and directions l(four locations and two directions provide eight possible values for l), for each of the time windows t (e.g. Tuesday 7:45-8:00, Monday 8:00-9:00, ...) and for all the before- and after-periods that were compared, the absolute evolution of the median speed $EFF_{l,t}$ was calculated as the difference between the median speed in the after-period and the before-period. From this result the absolute speed evolution during the same period on the comparison locations and directions c was subtracted, see Eq. 1 (Morris, 2007; Nuyts, 2006). The comparison locations were in each case the two directions of the comparison road in the same province as the experimental location l.

$$EFF_{l,t} = (V50_{l,af,t} - V50_{l,be,t}) - \frac{(\sum_{c=1}^{n} \tilde{n_c}(V50_{c,af,t} - V50_{c,be,t}))}{\sum_{c=1}^{n} \tilde{n_c}} \tag{1}$$

with

$$\tilde{n_c} = \frac{1}{\dfrac{1}{N_{c,be,t}} + \dfrac{1}{N_{c,af,t}}} \tag{2}$$

and

$V50_{\{l,c\},\{be,af\},t}$ = Median speed on l/c, before-/after-period, during t

$N_{c,\{be,af\},t}$ = number of observations (=passing vehicles) on c in the before-/after-period during t

$\tilde{n_c}$ = weighting of comparison road and direction c

n = number of comparison roads and directions for experimental road and direction l

The evolution of the speed for each comparison location was weighted according to the weighting factor $\tilde{n_c}$, that is the inverse of the sum of the inverses of $N_{c,t}$ for both the before- and the after-periods (Eq. 2). This reflects the idea that results that are derived from a larger number of observations are more reliable and should therefore weigh more when calculating a meta-result (Nuyts, 2006). In case of an increase of speeds, the sign of the resulting value is positive. In case of a decrease it is negative, in case of no evolution the value equals zero. The effect of the treatment on median speeds was assessed by using a non-parametric sign test (Washington et al., 2003) on the series of values for $EFF_{l,t}$. After analysing all time windows for a series of 7 days, the number of cases for each sign were added up for each before- and after-period. This resulted in a distribution of positive and negative signs or zeros. The idea of the sign test is to perform a binomial test on the proportion p of positive signs in the resulting values, with a null hypothesis of p=0.5. Since it was not a priori known whether the measure was likely to either increase or decrease speeds, a two way test was performed. When the measure would generate an increase in speeds, one would expect a majority of resulting positive signs whereas a decrease of speeds would be reflected in a majority of negative signs. In order to avoid small number biasses due to time windows with very little traffic, only those time windows were taken into account where at least 50 vehicles were counted. Figure 4 shows an example of the resulting effects on one location. Each data point reflects an individual value of $EFF_{l,t}$. Since a one-week-period was used there are at most seven data points per time window.

2.3 Results

After calculating effects per experimental road and per direction, results were aggregated to one single effect per time period, separately for the Line and the Number Markings. The aggregation was done by summing up numbers from the individual locations without an explicit weighting factor, resulting in a weighting by the number of available time periods. Tables 2 and 3 show the resulting effects, respectively for the Line and Number markings.

The last two columns of tables 2 and 3 reflect the absolute effects on the median speeds. The absolute effects are calculated as the average of the speed evolutions for each of the considered days and time windows. The last-but-one column provides the value of the evolution on the experimental roads compared with the evolution on the comparison roads, i.e. corrected for trend effects. The last column provides the speed evolution on the experimental locations without any correction.

Period	Nr. of periods	Nr. of periods with speed increase	Perc. periods with speed increase	Effect [1] (p-value)	Estimate with trend corr. (in km/h)	Estimate without trend corr. (in km/h)
0-1	292	184	63%	+(<0.01)	1.90	−1.01
1-2a	226	98	43%	−(0.05)	−0.37	−0.58
1-2b	227	109	48%	0 (0.60)	−0.73	−1.86
0-2a	229	123	54%	0 (0.23)	0.37	−1.87
0-2b	233	136	58%	+(0.01)	0.88	−2.76

[1] 0 = no sign. effect, + = increase of speeds, − = decrease of speeds

Table 2: aggregate effect of the Line markings

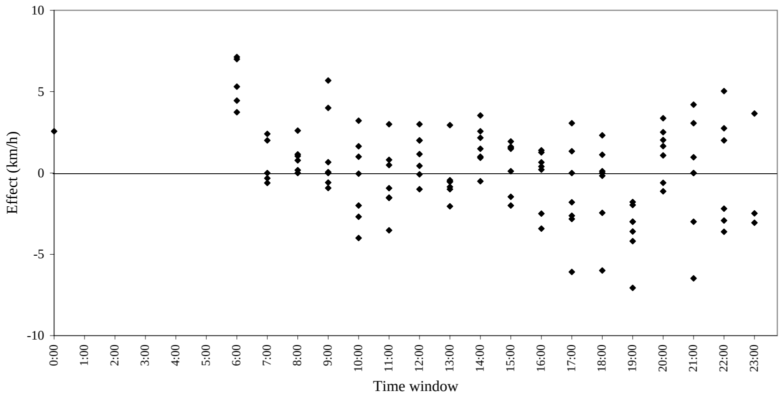

Figure 4: Effect Line markings on N28+ in period 0-2a

Period	Nr. of periods	Nr. of periods with speed increase	Perc. periods with speed increase	Effect[1] (p-value)	Estimate with trend corr. (in km/h)	Estimate without trend corr. (in km/h)
0-1	406	214	53%	0 (0.25)	−0.22	−0.98
1-2a[2]	141	85	60%	+(0.01)	0.19	−0.66
1-2b[2]	161	122	76%	+(<0.01)	2.09	2.13
0-2a[2]	141	43	30%	−(<0.01)	−1.22	−2.63
0-2b[2]	161	93	58%	+(0.04)	0.88	0.02

[1] 0 = no significant effect, + = increase of speeds, − = decrease of speeds
[2] data available for one segment only

Table 3: aggregate effect of the Number markings

As an alternative to the analysis with the sign tests, another analysis strategy was adopted by executing a series of multiple linear regression models with the speed measurements on the experimental location ($V50_{l,\{be,af\},t}$) during a certain period (e.g. 0-1, 0-2a etc.) as dependent variables. Explanatory variables were the speed measurements on the comparison locations ($V50_{c,\{be,af\},t}$), dummy variables for the period (0, 1, 2a, 2b) and two class variables expressing the day of the week and the hour of the day. The resulting parameter estimates of the dummy variables indicating the period were used as the best estimates for the effect of the measure. The results of the alternative analysis are not provided for reasons of convenience. Although the parameter estimates were generally somewhat different from those in the sign tests and they changed in a limited number of cases even from a positive to a negative sign or vice versa, the results did basically not deviate from the results of the sign-tests.

3 Simulator study

The driving simulator study was set up to evaluate the effects of the proposed markings on speed behaviour of non-informed road users. Compared to other designs such as observational studies, the experimental setting that could be created in a driving simulator provided important advantages as confounding factors could be kept under control and effects could be isolated and interpreted (Kaptein et al., 1996; Godley and Triggs, 2002; Charlton, 2007). Moreover the experimental setting in the driving simulator allowed to obtain specific information on drivers characteristics such as age and gender, to manipulate the level of mental effort and to ask drivers for feed-back after finishing the experiment. Furthermore, the used simulator equipment allowed to collect multiple and detailed speed measurements, which was not possible in the field experiment. A drawback of simulator studies could be their possibly reduced validity since additional assumptions are needed in order to generalise the results. Validity aspects of simulator studies have been discussed earlier. The predictive or behavioural validity of simulator studies has two components: an absolute and a relative validity (Godley and Triggs, 2002). The absolute validity can be explained as the concordance between behaviour in a simulator environment and what is noticed in real-world practice. The relative validity refers to the power of the setting to detect differences between different experimental conditions (Törnros, 1998). The implicit hypothesis in the simulator study was at least an appropriate relative validity.
When comparing the field study and the simulator study, one must be aware that not exactly the same conditions were compared. The used combinations of markings and signs were different: in the field experiment only C43 signs were used whereas zone signs were applied in the simulator on the segments with the additional road markings.

3.1 Experimental design

3.1.1 Research subjects

Through announcements in newspapers and on websites, an advertisement in a local information magazine and posters, 33 participants were recruited. Useful data could be collected from 30 subjects, of which 27 male and 3 female. The average age was 41.6, with a range between 20 and 77. All participants held a car driving license for at least one year (on average 20.5 years). None of the participants was aware of the aim of the study.

3.1.2 Driving simulator

The experiment was conducted in the driving simulator of the Flemish Automobile Association (VAB), located near Antwerp, Belgium. The mock-up of this driving simulator is based on a Volkswagen Golf. Visualisation was realised by a three-channel system, projecting complementary images on three flat projection screens (figure 5).

3.1.3 Driving tasks and instructions

Participants were asked to perform six different drives in the simulator. They were instructed to drive as close as possible to the indicated speed limit but otherwise to drive as they would normally do, to comply to all traffic rules and to continue driving until asked to stop. Participants were told that the purpose of the study was to investigate the effect of mental effort on driving performance. Participants were also informed that certain design elements could vary throughout the different drives, but no specific information was provided about the road markings.

Apart from the driving task, a secondary task was introduced in half of the drives. The secondary task consisted of a series of simple arithmetic tasks, the Paced Serial Addition Task (PASAT) (Gronwall, 1977). A series of numbers between 1 and 10 were read aloud and the participants were requested to respond with the sum of the last number and the previous number (e.g. 1 5 3 7 yields 6 8 10 etc.). Numbers were presented at a constant frequency of 2 or 3 seconds, depending on the participant. The aim of the arithmetic task was to increase mental effort by charging the working memory and requiring continuous attention. The performance on the secondary task was not explicitly measured.

3.1.4 Routes

A basic route of approximately 7 km was simulated, representing a slightly curved road with two lanes (one in each direction) and consisting of four segments: a 90 km/h segment (2 km), a first 70 km/h segment (3 km), a signal-controlled intersection (signals always on green) and a second 70 km/h segment (2 km). Three versions of this basic route were created: the Signs-route, the Numbers-route and the Lines-route. The Signs-route simulated the currently applied system with C43 speed signs at the 90-70 km/h transition and a repeated sign beyond the intersection. For both the Numbers- as well as the Lines-routes, the 90-70 km/h transition was marked with the speed zone sign (figure 6). This sign, although not typically used on 70 km/h roads, exists in the highway code and indicates a speed zone. It remains, unlike the C43-sign, applicable until it is explicitly suppressed by an 'end of zone' sign. In the Numbers- and Lines-routes the experimental road markings (i.e. the same number 7 or line markings as in the field experiment) were added whenever the speed limit was 70 km/h, thus in segments 2, 3 and 4.

Figure 5: Driving simulator

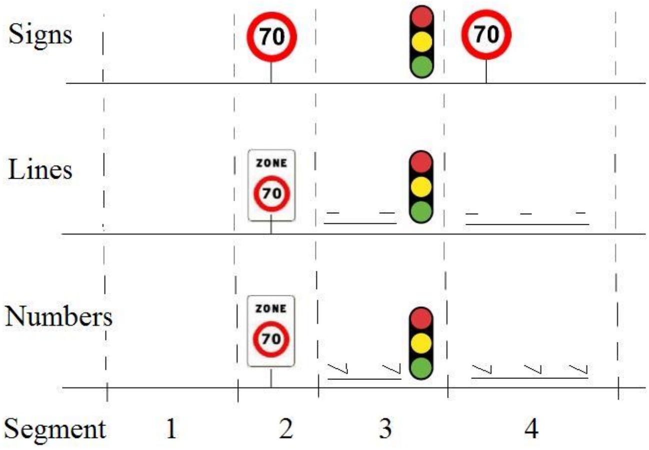

Figure 6: Experimental routes

3.1.5 Registered variables

Driving behaviour was measured in both an objective and subjective way. Objective data on location, speed and lateral position were registered 30 times per second. The subjective evaluation of the driving performance was collected through a RSME-questionnaire (Rating Scale for Mental Effort, Zijlstra and Van Doorn, 1985), which participants completed after every session. The RSME is a one-dimensional ratio scale on which the score for the mental effort is indicated trough a vertical line with indications from 0 to 150.

3.1.6 Design

Crossing the two independent variables Routes (with three possible values: Signs, Numbers and Lines) and Mental Effort (with two levels: Low and High, i.e. without or with secondary task) yielded six experimental conditions. All participants performed six drives, each of them corresponding with one experimental condition. In order to minimize order and learning effects, the sequence of the drives was counterbalanced with the following restrictions: (i) the factor Mental Effort was blocked in such a way that the three drives without secondary task were always done before the three drives with the secondary task (or vice versa), (ii) the order of the three Routes (e.g. Signs - Numbers - Lines) was not allowed to be equal for the two blocks.

3.1.7 Procedure

After a short introduction some personal characteristics were recorded (gender, age and the number of years since obtaining the driving license) and the participants signed an informed consent-declaration. Subsequently a short test drive was made in order to familiarize participants with the simulator. Then they performed the six experimental drives. After each drive there was a small break during which the participants completed the RSME-questionnaire. Immediately before the first drive of the block with the high mental workload, the secondary task (PASAT) was explained and tested. Finally, after the last drive the participants were interrogated about the possible changes they had noticed throughout the different drives. They were explicitly asked about the changes in the road markings. All together, the experiment lasted about one hour per participant.

3.2 Results

3.2.1 Speed

Speed data were analysed separately for each of the four segments, in their order of occurrence.

Segment 1: 90 km/h The first segment contained data starting 500 m after departure until 100 m before the 90-70 km/h transition. This part was identical in all routes and therefore interesting in order to check the reliability of the results as these should be equal for all drives in the same conditions of mental effort. A repeated measures-ANOVA on the mean speed per participant was conducted for each of the six drives. The ANOVA did not show a main effect by

Route, $F(2,58)=1.54$, $p=0.22$, nor an interaction effect, $F(2,58)=1.03$, $p=0.36$. An increasing level of Mental Effort showed a significant downwards effect on the mean speed, $F(1,29)=12.31$, $p<0.01$, with a value of 86.44 km/h (Low Mental Effort) and 83.07 km/h (High Mental Effort).

Segment 2: transition 90-70 km/h Approximately 2 km after departure there was a transition from 90 to 70 km/h. The indication of the transition differed according to the route. In the Signs-route the indication was done by the C43-sign. In the Number- and Line-routes it was done by the zone sign, supported by the two different types of experimental road markings. Figure 7 and 8 show the speed evolution (average for all participants per 5 m) from 200 m before the transition until 200 m beyond the transition. The speed reduction in the Signs-route appears to have been more explicit than in both other Routes and the speed reduction was reached earlier. In the conditions without secondary task, the speed level at the transition point (distance 0) was lower in the Signs-route (72.7 km/h) than in the Lines- (77.2 km/h) or Number-routes (76.7 km/h). In the condition with the secondary task the speeds in the Sign- and Line-routes were lower than in the Number-route. Figure 8 shows that, already from before the transition, speeds in the Line-route were lower than in both other conditions, which is not straightforward to interpret. Analysis of the individual results revealed that drivers showed divergent reactions to the higher mental effort. While some started to drive slower, two participants speeded up to 120 km/h. Another result was the effect of the increased mental effort. In the condition with the secondary task, reactions to the lowered speed limit were slower, leading to higher speeds on the transition (e.g. in the Signs-route: 80.5 km/h versus 72.7 km/h).

Segment 3: 70 km/h Figure 9 shows the average results for the third segment. The speed data were measured from 100 m beyond the 90-70 km/h transition till 100 m before the intersection. The ANOVA-analysis revealed no significant effect of the different routes, neither as main effect, $F(2,58)<1.58$, $p=0.21$, nor as interaction with Mental Effort, $F(2,58)<1$. Manipulation of the mental effort as such had a significant effect, $F(1,28)=7.08$, $p=0.01$, with mean speeds of 74.3 km/h (High Mental Effort) and 70.48 km/h (Low Mental Effort). Furthermore standard deviations of speeds were calculated as an indication of the stability of the speed level throughout the road segment. Although values for the higher mental effort turned out to be always somewhat higher, ANOVA-analysis of these results showed no significant differences among the different conditions.

Segment 4: 70 km/h - beyond intersection Mean speeds in the fourth segment were analysed from 100 m beyond the intersection until 200 m before the end of the route. Here the effect of Route (Signs vs. Lines vs. Numbers), $F(2,58)=10.59$, $p<0.01$ was significant with higher speeds on the Lines and Number routes. Mental Effort was not significant, $F(1,29)=2.5$, $p=0.12$, neither was the interaction between Routes and Mental Effort, $F(2,58)< 1$.

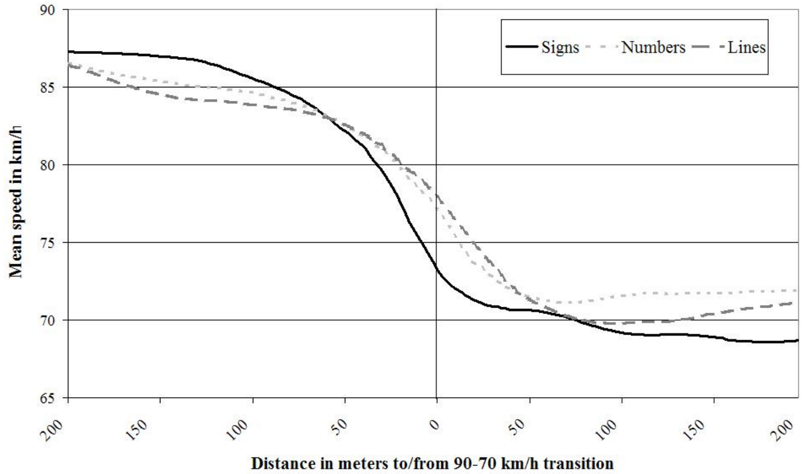

Figure 7: Mean speed on 90-70 transition - Low mental effort

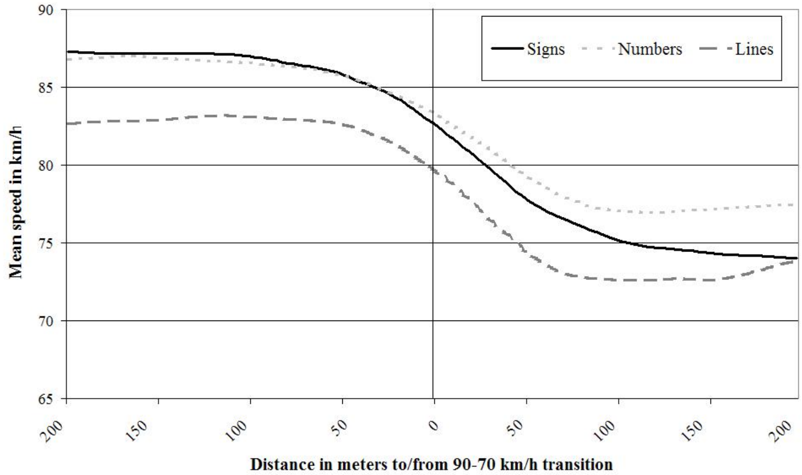

Figure 8: Mean speed on 90-70 transition - High mental effort

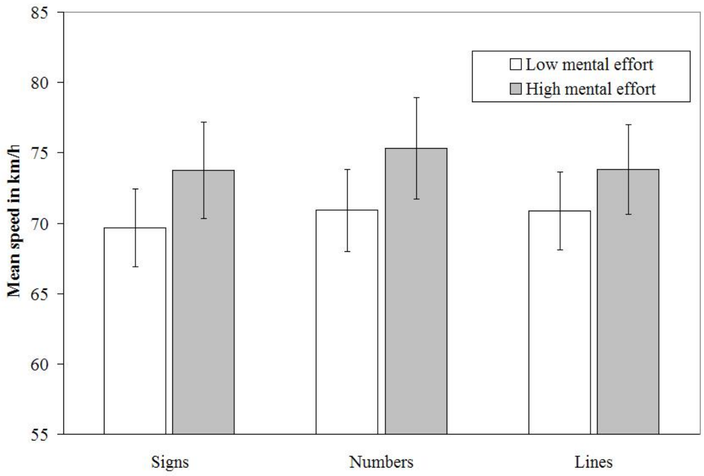

Figure 9: Mean speeds and standard deviations (error bars) in segment 3 for the six conditions

3.2.2 Lateral position

A two-way repeated measures-ANOVA of the mean lateral position in the different route conditions on the first 70 km/h segment showed a significant main effect on the lateral position, $F(2,58)=4.31$, $p=0.02$. The mean lateral position shifted closer to the centreline when the additional markings were present (i.e. in the Number and Line routes). The mental effort did not influence the lateral position, $F(1,29)<1$ and the interaction between Route and Mental Effort was also not significant, $F(2,58)=1.57$, $p=0.22$. Exact values of the measured lateral position are provided in table 4.

3.2.3 Subjective experience: mental effort

After each drive the experienced mental effort was measured through the RSME. As expected, there was a clear effect for the variable Mental Effort, $F(1,29)=265$, $p<0.01$. However, no significant difference between the three types of routes was found, $F(2,58)<1$. At the end of the experiment each driver was asked whether differences were detected between the different drives. More than half of the participants did not provide any of the relevant factors in the study (markings or signs). After explicitly bringing under attention the markings, still one third of the participants did not report having noticed any of the additional markings.

4 Discussion

4.1 Data quality and validity

Weaknesses in the data quality of the field study cannot be excluded. Although efforts were made to keep the experimental conditions as much as possible under control, one cannot exclude in a real world experiment some confounding factors such as periodical road maintenance or incidental traffic congestion that

Route	Mean[1] lateral position (*Stand. dev.*)	Min-max[1]
Signs	1.828 *(0.106)*	1.507-2.172
Numbers	1.808 *(0.119)*	1.474-2.131
Lines	1.798 *(0.124)*	1.440-2.023

[1] values without dimension, relative distance to centreline. The larger the value, the larger the distance between the vehicle and the roadway centreline.

Table 4: Average lateral position (with standard deviation) and minimal and maximal values throughout the sample for the three different routes

may have disturbed the data collection process, both on the experimental locations and on the comparison locations. Such factors could explain why results appear to be rather inconsistent throughout the different measurement periods (0-1, 1-2a,...). Supposing that the effect of the Line and Number markings was a priori not expected to be so much different, it is rather surprising that the sign of the effect for both types of markings does not correspond for periods 0-1, 1-2a, 1-2b and 0-2a. Only the longer-term effect (0-2b) shows a consistent, but limited increase (+0.88 km/h) in median speeds for both types of markings. However, in the regression analysis the 0-2b effect for the Line markings was insignificant and showed even a negative sign (-0.12). Moreover, the estimates for the Number markings are based upon the results of one segment only, which makes chance effects more likely.
The complexity of the data collection procedure appeared to be another relevant factor. The used equipment in the field study could provide only median speeds per 15 min or 60 min and measurements were restricted to one point per road. In contrast to this, the simulator software provided detailed data on individual speed and lateral position every 5 m throughout the whole distance, which facilitated largely the analysis procedure.
Efforts were made to match the road environment in the simulator as close as possible to the real-world design, i.e. to aim absolute validity. But a warranty about absolute validity cannot be given without a formal check. It is for example unclear which differences might exist in the conspicuity of the interrupted lines or numbers 7 in a simplified simulator environment compared to the more complex reality. This element of uncertainty must be kept in mind whenever results of the simulator study are interpreted.
Another aspect relates to the relative validity of the simulator study. The setting appeared to be sensitive enough to detect effects when variables were manipulated. Examples are the shift in lateral position that was noticed when the Line and Number markings were present and the effects of the modified mental effort. Furthermore no significant differences were found in the results for the first 90 km/h segment that was kept constant throughout the different routes. Since small effects could be detected and unchanged conditions seemed to in-

duce unchanged behaviour, the assumption of an appropriate relative validity seems to be supported.

4.2 Effects on mean speeds and lateral position

The field study aimed to detect possible effects of two types of additional road markings on mean speeds. From the knowledge that mean speeds on 70 km/h roads are generally above the limit (see introduction), the underlying hypothesis was that road users are not always aware about the prevailing speed limit and that more permanently available information would lead to improved speed behaviour in terms of adhering to the 70 km/h speed limit. This hypothesis is not supported by the data, neither in the field study nor in the simulator study. No decrease in mean speeds was reached. The absolute effect estimates in the field study are small (generally with an absolute value of less than 1 km/h), certainly not always negative and not consistent throughout the periods and for both types of markings. Limitations in the data quality and availability may account for the inconsistency in the results. If the hypothesis can be accepted that the data quality was at least sufficient, the results don't seem to show a substantial effect of the additional markings on speed behaviour.
The three routes (Signs, Numbers, Lines) in the simulator study did not differ much with respect to actual driving behaviour. The classic C43 speed sign was more effective than the speed zone sign at the transition point itself. Decelerating started earlier and was faster. However, in the 70 km/h segment that followed the transition no significant differences were found for mean speed, mean standard deviation of speed or mean standard deviation of lateral position. But there was a shift in the mean lateral position. In the conditions with the additional markings participants drove on average closer to the centreline than without the markings. This suggests that the markings were at least in some way detected, but that this was most likely not a conscious process, given the few participants that actually reported having noticed them.
Summarizing, a null effect of the markings on speed behaviour seems to be plausible. Also Charlton (2007) found that the addition of some extra elements (herringbones) to longitudinal road markings was not able to influence speed behaviour whereas lateral position clearly was affected. van Driel et al. (2004) made a meta-analysis of studies that evaluated the effects of edgelines on speed and lateral position. The meta-analysis could not show clear results concerning the effect of adding an edgeline to a road where already a centerline was present, which was the case that was closest to the one in the present study. Theeuwes and Godthelp (1995) assume that the nature of contextual effects on the processing of traffic scenes is the result of an interaction between incoming perceptual information and the higher level memory representations. A lack of conspicuity of the markings could be an important factor in this study and could explain a possible null effect. Drivers simply did not notice the presence of the markings. However, the simulator study indicated that the additional road markings were at least sufficiently visible to induce a lateral shift towards the centreline. This suggests that the markings were physically sufficiently visible. The lack of conspicuity might be due to physical properties of the markings themselves, but visual selection also depends on the demands of the search task, meaning that expectations that are created by the traffic environment determine to which extent infrastructural elements are perceived (Theeuwes and Godthelp,

1995). This could mean that the stimulus from the markings was present but was possibly too weak to change the perception of the traffic environment and subsequently to change expectations and resulting speed behaviour. Several authors stated that unexpected but relevant information may be missed by drivers since drivers get used to a certain road environment and experienced drivers develop fixed routines for searching information (Van Elslande and Faucher-Alberton, 1997; Martens and Fox, 2007; Herslund and Jørgensen, 2003). This effect is likely to exist in this case as probably a large proportion of road users was already frequently using the experimental roads or similar roads before the experiment started. A furthermore contributing factor to incorrect expectations might be that speed limits on the four study locations were lowered only a few years ago from 90 to 70 km/h whereas no specific changes in road design were made.

4.3 Mental effort and task performance

The inversely related effect of mental effort to mean speed that was noticed in segment 1 was found in several studies (e.g. Brookhuis et al., 1991; Horberry et al., 2006b). From a theoretical point of view it has been stated that drivers are sensitive to task difficulty and attempt to maintain their experienced level of difficulty within a margin of acceptability (Fuller, 2005). However in the segments 2 and 3 an opposite effect occurred. Higher mental effort correlated with higher speeds. The adaptation to the speed limit change in segment 2 was slower in the conditions with the higher mental effort. Also speeds in segment 3 were higher in the conditions with the higher mental effort. In both cases this is likely to be the result of a weaker task performance since the instruction was given to the participants to drive as close as possible to the speed limit and speeds in the conditions with higher mental effort deviated more from the speed limit. The slower adaptation and the weaker performance could therefore again be explained by the higher part of the driver capability that is needed to accommodate the higher task demand. A similar reduced driver responsiveness to traffic conditions in circumstances with higher mental effort was found elsewhere (Haigney et al., 2000; Horberry et al., 2006a; Recarte and Nunes, 2002). In other words, the constant between the effects of the higher mental effort in segments 1, 2 and 3 was not a similar absolute effect on mean speeds but was in the different cases a weaker driving performance, resulting in lower - but more deviating from the 90 km/h limit - speeds in the first segment and in higher - but more deviating from the 70 km/h limit - speeds in the second and third segment. This statement relies on the assumption that the preferred speed on the depicted type of roads lies somewhere between 70 and 90 km/h. Goldenbeld and van Schagen (2007) reported an average preferred speed of 87.9 km/h, with a variation from 71 till 97 km/h, on 27 rural road scenes with a posted speed limit of 80 km/h.

4.4 Information

The a priori expectation was that the stimulus offered by the information panel in the field experiment would be strong enough to explicitly draw attention on the markings and to induce the desired speed decrease. According to the results, the aimed speed decrease was not reached. Different interpretations for

this result are possible. Firstly, it is possible that the information panel failed to draw attention or to draw explicit attention to the markings. Although they could have noticed the information panel, drivers were perhaps not aware of the exact meaning and did not interpret what they saw in the way that it was intended. An alternative explanation is that, when one assumes that the information panel brought a sufficiently clear message, drivers did not show the expected behaviour, but contrarily maintained deliberately their existing behaviour.
Unlike the field study, through the installation of the information panel, drivers in the simulator study were not informed about the function of the additional markings since it aimed to evaluate spontaneous response to the markings. Compared to the traditional system in the Signs route (repeated C43 sign) of the simulator study, mean speeds in the Numbers and Lines routes (speed zone sign remained applicable, but was not repeated) were significantly higher in the fourth segment that was located beyond the intersection and still had a speed limit of 70 km/h. In 15.8% of the Numbers and Lines routes the driver accelerated above 80km/h immediately following the intersection (compared to 1.6% in the Signs route). This confirms the need for an appropriate decision supporting mechanism when explicit information on speed limits, like a repeated C43-sign, is missing.

5 Conclusions

The markings did not elicit the desired speed behaviour. The results of the field study show no clear effect and certainly not a substantial effect of the markings on the speed behaviour. Flaws in the data collection process could explain some inconsistencies in the results. This indicates at least one important restriction of observational field studies in comparison with experimental simulator studies. The results of the simulator study, with slightly different stimuli from the field study, indicate no effect on speed behaviour due to the additional road markings. The only explicit effect of the road markings that could be noticed was a shift in lateral position towards the centreline. Throughout the simulator study a higher mental effort induced a weaker task performance.
When appropriately informed it could be possible that road users do adapt their speed behaviour when additional markings are present. In the simulator study this condition was not tested. In the field study - where an information panel was used - neither this condition seemed to be able to induce the targeted behaviour.

6 Acknowledgements

This research was funded by the Policy Research Centre for Traffic Safety, the Flemish ministry of Mobility and Public Works - Roads and Traffic Agency and by the Flemish Automobile Association (VAB). The paper benefitted from the comments of three anonymous reviewers.

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