SEQUENTIAL ADVANCED GUIDE SIGNING FOR WORK ZONE RELATED REROUTING ON HIGHWAYS: THE EFFECT OF LONGITUDINAL LOCATION ON THE DRIVER' S TRAJECTORY CONTROL

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ABSTRACT

This study examined the effects of a sequenced triple (i.e., announcement, instruction, marker) sign configuration for advanced guidance in a work zone related rerouting scenario on longitudinal and lateral driver control. The longitudinal distance of only the second (instruction) sign varied (i.e., 500m vs. 1000m vs. 1500m before the target exit) whereas it was held constant for the first (announcement) sign (i.e., 2000m before the exit) and the third (marker) sign (i.e., 50m before the exit). It was expected that the second sign would affect driver's longitudinal and lateral vehicle control and that the effect would be dependent on the sign's longitudinal location. 30 subjects completed a 14km test-drive on a driving simulator with three exits to be taken.

Following our expectations, the second sign had an effect on longitudinal (i.e., mean speed and SD for acceleration/deceleration) as well as lateral (i.e., number of lane switches to the right) driver behavior. Furthermore, this effect depended on the longitudinal location of the second (instruction) sign. From a comparison of the three locations it was concluded that placing the second sign at 1000 meters from the exit was the most preferable option in terms of traffic safety and flow.

1 BACKGROUND

Work zone related crashes on highways are a major issue in terms of road safety management. It has been argued that this is largely due to the interference of work zones with normal traffic flow. More specifically, work zones imply temporarily modified and complex road geometry (i.e., multiple splits, closed off driving lanes, etc.) with small warning times (*1*), and this induces both abrupt speed alterations and last moment movement decisions, reducing the likelihood of a smooth and stable shift of traffic, which results in an increased risk for rear-end and sidesweep crashes (*2*).

This explains why improving safety and operational efficiency of traffic flows at work zones still is one of the major challenges in traffic engineering. One way of dealing with safety at highway construction zones is to have road users simply navigate around them *(3).* This particular form of incident management is referred to as *rerouting* and diverts drivers from the primary route onto a secondary street network and then back to the original route. The primary advantages of this system are the avoidance of a potentially direct conflict between construction zone workers and motorists as well as a lowered congestion risk with drivers being caught in upstream traffic jams on the primary route.

In a highway context, accessing the alternate route means having to take a right-lane exit while driving on a single direction multilane road with the outer right lane serving as a drive through for traffic that is not to be rerouted and therefore continues its normal trajectory *(4, 5*).

In order for drivers to optimize their decision making and actions, it is essential that they are aware of the diversion route on time *(6).* The basic theoretical assumption behind the principle of advanced warnings is that they *prepare* the driver and thereby maximize the chance of appropriate actions being undertaken under dangerous and/or unexpected circumstances *(7).*

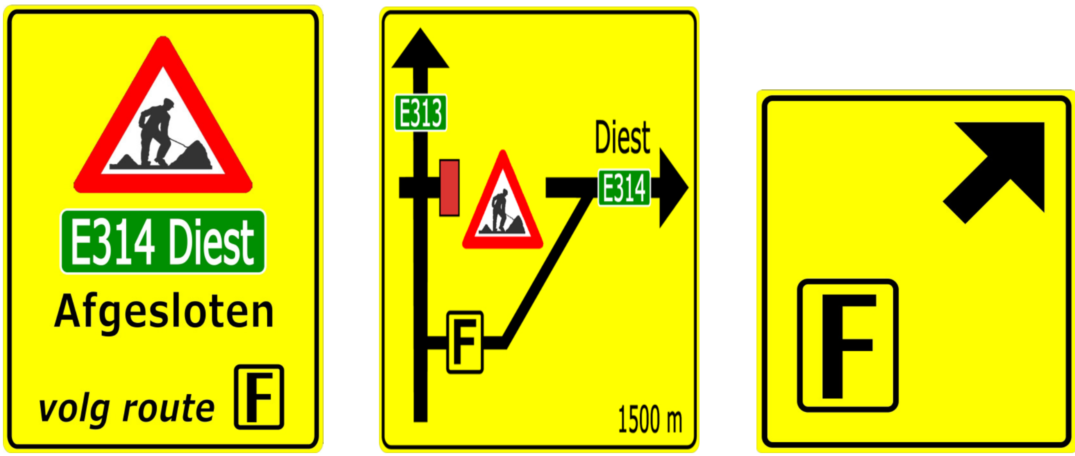
By contrast, late recognition of the exit lane makes drivers execute risky weaving maneuvers to enter the desired lane *(8),* and motorists waiting until the last moment to change lanes may create a bottleneck and thereby reduce a smooth shift of traffic. Finally, if there isn't enough time to make a move, drivers must continue in the same travel direction until they have the opportunity to turn around which will cause an increase in both emissions and traffic volume in the opposite direction *(9).*

For the above problems to be avoided, additional advanced guidance information is essential *(10*). The safety effects of advanced warning devices have been demonstrated before *(11*). In general, they induce speed reduction and earlier lane change which avoids sudden stops and erratic or last-minute maneuvers.

Although rerouting has become a popular practice throughout various regions in Europe as well as the U.S., many European countries have developed their own signing system since there is no uniform set of regulations or guidelines to be followed. As a result, different signing approaches co-exist without really knowing what might be considered as best practice. The system of advanced guide signing that will be evaluated in this study is currently in use on the Flemish road network, which is among the most dense and intensively occupied networks throughout Europe.

The basic principles behind the Flemish approach have been outlined by a workgroup of specialists in traffic safety and engineering *(12).* The signing system they worked out is implemented more specifically for cases where highway traffic is to be rerouted due to the occurrence of a planned incident, such as road construction and maintenance works, or when highway traffic is to be guided towards big local events such as music festivals, pop concerts or sport manifestations.

More in detail, highway rerouting in Flanders is based on the principle of *advanced* guide signing with the exit leading to the diversion route being preceded by a sequence of three different signs. Each of these three signs serves a different purpose, i.e., announcing, instructing and marking, and the alternate route itself is represented by a predetermined code letter. Figure 1 visualizes these signs more in detail.



(a) **(b)** **(c)**

FIGURE 1 Work zone related rerouting signs: (*a*) first (announcement) sign, size 4m by 4m, (*b*) second (instruction) sign, size 4m by 4m, and (*c*) third (marker) sign, size 1,6 by 1,7m.

Figure 1*a* pictures an example of the so-called *announcement* sign which indicates how motorists cannot access highway E314 towards Diest by means of the usual exit, due to road works. Instead, they have to take another exit and follow an alternate route towards the E314 (represented from here on by the code letter F). This sign is located the furthest away from the exit to be taken and therefore is the sign first met by the concerned drivers. Throughout the remainder of the paper, it will be referred to as *sign 1*.

Figure 1*b* represents an example of the *instruction* sign. This sign follows the previous one and its message varies in function of what the precise reference situation is like. The context this example refers to is one where the exit to be taken normally in order to reach the desired destination is blocked due to construction works. Therefore, concerned drivers will have to leave the highway earlier in order to avoid they will have to turn around. As can be seen, the major difference with the previous sign is that it gives specific instructions to the drivers as to how (i.e., by means of the first upcoming right-lane exit) and when (i.e., within 1500m) they will be urged to leave the current route (i.e., the E313) in order to access the diversion route which is indicated by the code letter F and leads towards the E314 that brings them to the target destination (i.e., Diest). From now on, this sign will be referred to as *sign 2*.

Figure 1*c* illustrates the third *marker* sign which indicates the exit that provides access to the diversion route and is located near to it. As can be seen, its message is limited to the code letter of the alternate route (in this example, code letter F) and an arrow urging drivers to take the right exit. From hereon, this sign will be referred to as *sign 3*.

2 PROBLEM STATEMENT

Interestingly, the instructions formulated by the responsible workgroup serve only as practical guidelines instead of strictly regulating how the signing of highway rerouting should be executed. Although the design of the signs (i.e., background color, size, etc.) as well as the messaging (i.e., symbols, style, font, etc.) are clearly highlighted, there is no exact information on the longitudinal location of the signs (i.e., the distance separating the signs from the exit). While the instructions for sign 1 (i.e., sign 1 should appear at least at about 2000m ahead of the target exit) and sign 3 (i.e., sign 3 should be located at about 50 to 100m ahead of the exit) are neither compulsory, nor very precise, for sign 2, it is fully up to practitioners to decide on where it should be located. In addition to that, the efficiency of the longitudinal locations mentioned has not been empirically tested yet. In our opinion, this is problematic for two reasons:

Firstly, prior research suggests that the efficiency of advanced diagrammatic guide signing is indeed determined by its longitudinal location. In their study on guide signs for two-lane exits with an option lane, Upchurch et al. *(5)* concluded that longitudinal location of the lane designation signs with respect to the gore was very important. More precise and evidence-based instructions on where to locate the different signs is therefore highly recommended.

Secondly, and even more important, the lack of instruction on the longitudinal location of the second (instruction) sign is a serious shortcoming because, within the triple sign sequence, this is the one that urges drivers to make the appropriate adjustments and informs them on when and how they would best do so. All together, this makes the Flemish approach towards diagrammatic advanced guide signing for highway rerouting a relevant study case.

3 OBJECTIVES

This paper aims contributing to the existing literature on rerouting in three different manners. Firstly, by means of the situational context selected. We study the effect of advanced diagrammatic guide signing in a rerouting scenario with drivers urged to take a right-lane exit on a two-lane highway with the right lane serving as a drive through option. To the best of our knowledge, the principle of rerouting within a context alike has not yet been examined before. Notwithstanding, the potential danger in terms of safety and flow for situations such as these is substantial. The main problem resides in the likelihood of two vehicles on the left and right lane respectively, vying for a single lane while approaching the exit, creating turbulence in the traffic stream. Besides that, there is a potential collision danger for vehicles using the right lane as a drive through on the one hand and motorists trying to vacate the left lane in order to take the exit on the other.

Secondly, by simultaneously analyzing both the longitudinal and the lateral dimension of the driver's so-called *trajectory control*. Trajectory control is a concept proposed by Rosey et al. *(13)* referring to how motorists manage vehicle movements while driving. The authors explain how vehicle maneuvering can be problematic both longitudinally and laterally (i.e., phenomena referred to as *shockwaving* and *wandering out*). In their opinion, studies where the two dimensions have been investigated together are rather exceptional. This is unfortunate since information on a combination of both dimensions of driving performance would improve our understanding of the problem situation at hand and upgrade the quality of advice offered to policy makers.

Thirdly, by studying the efficiency of diagrammatic guide signing in function of the signs' longitudinal location. Apart from a few exceptions *(4, 14, 15)*, there has not been a systematic evaluation of its effect on driving behavior yet.

4 RESEARCH QUESTIONS

Turning to the precise research questions addressed by this paper, we retake the accent is on the role of the signing's longitudinal location as a determinant of drivers' lateral and longitudinal trajectory control. The approach for advanced signing under study here consists of three consecutive signs of which the second sign is the key-stimulus in terms of changing the driver's behavior.

Therefore, we will manipulate the longitudinal location of this sign in particular with the locations of the other two signs held constant and in line with the existing guidelines (more details on the sign configuration can be found under the methodological section). In terms of data analysis, we will look at effects generated by the first and second sign only, because, contrary to the third (marker) sign which serves as an indication of the target exit, the first two are the ones that really have to *prepare* the drivers for the upcoming situation. Accordingly, we formulate our research questions as follows:

1. Do the first and the second reroute sign affect driving behavior as reflected by a pre-post difference of longitudinal and lateral control?
2. Does the effect of the second sign vary in function of its instruction regarding the distance before reaching the exit?
3. At which locations along the ride does driving behavior differ depending on the instruction on the second sign, as reflected by differences between three conditions?

5 METHODOLOGY

5.1 Participants

Thirty-three volunteers participated in the study. All gave informed consent. Three participants were excluded; one discontinued the experiment due to simulator sickness, and two did not follow the instructions of taking the reroute-exits (see below). Thus, 30 participants (ages 18-63, mean age 35, 12 female) remained in the sample. All had (corrected to) normal vision.

5.2 Driving Simulator

The experiment was conducted on a high-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 and auditory 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. The sounds of traffic in the environment and of the participant's car were presented. The projection screen offered a resolution of 1024 × 768 pixels on each screen and a 60 Hz refresh rate. Data were collected at frame rate.

5.3 Sign configuration

As already indicated, re-routing was done by use of three successive signs. The first (announcement) and the third (marker) sign were placed at fixed distances from the exit, following the aforementioned guidelines: the announcement sign was presented 2 km before the exit, and the marker sign was presented 50 meters before the exit. Placement of the second (instruction) sign was the variable of interest in the present study and varied depending on condition: it was placed at 500 (5-condition), 1000 (10-condition), or 1500 (15-condition) meters before the exit. Only the second sign varied in placement regarding the distance between the sign and the exit. There were three conditions, one for each zone, as the distance was.

5.4 Scenarios

All scenarios were motorway-scenarios (straight road and curves) with a speed limit of 120 kph, consisting of two lanes (presented on the left-side of the screen) used by traffic coming from the opposite direction, and two lanes (presented on the right) in the direction of travel. These were separated by a median strip of green. Each lane had a width of 3.5 meters, and the median strip had a width of 7 meters. There was a light volume of surrounding traffic, based on existing traffic-counting on a highway in the neighborhood of where testing took place. When the driver was driving on the right lane, in the left lane occasional vehicles traveling at 120 kph (automobiles) or ±100 kph (trucks) passed the driver.

The main session was divided in a practice session and an experimental session. The practice session consisted of two scenarios. First, a short and sober scenario (2.1 km, 4 minutes) without any curves, signs, and other road users was presented to acquaint drivers with the experience of driving in a simulator, and to get used to the mock-up before participation in the experimental session. Then a longer practice scenario (14 km, 15 minutes) was presented that was similar to the scenarios in the experimental session and served to acquaint drivers with this specific type of scenario.

The experimental session was 13.5 km in length, consisting of 3 zones of 4.5 km in length. In each of the 3 zones, a traffic diversion was presented, and each zone corresponded to one of the three conditions. Every subject thus participated in each of the three conditions, and order was counterbalanced between-subjects.

During the practice session and the experimental session, drivers were free to change lane, and instructed to drive as they would normally do, following all traffic regulations. In addition they were informed about the re-routing and the signs that were used to indicate rerouting in the scenarios. They were instructed to read and follow the signs and to take the exits that belonged to each of the three traffic diversions. To ensure that participants were aware of re-routing, only drivers that took each of the three exits were included in the analyses.

5.5 Data collection and analysis

Driver performance measures of longitudinal control and lateral control were collected. Longitudinal control was measured by driving speed, its standard deviation (SD), longitudinal acceleration/deceleration, and its SD. Lateral control was measured by the number of lane switches and the time spent on the left/right lane. In addition, the position at which drivers made the last lane switch to the right lane was calculated for each of the three conditions to determine if the distance between this point and the exit varied in function of condition.

Data were collected during the experimental session in each of the three 4.5 km condition zones. The first 2 km served as 'filler' pieces, ensuring that drivers were immersed into driving before the first re-route sign was approached. The following 2.5 km in each zone, from 500 meters before the first sign until the end of the zone where the exit was presented was divided into ten 250-meter segments of interest. Longitudinal and lateral measures were averaged for these segments.

To determine the effect of the first and the second reroute sign on driving behavior, and test if the effect of the second sign varies in function of condition (research question 1), mean values of the longitudinal and lateral measures in the 250-meter segment before and after these signs were entered in an analysis with within-subjects factors Condition (3: 5-condition, 10-condition, 15-condition) and Pre-Post measurement (2: Pre-250-meter segment, Post-250-segment). Longitudinal measures were analyzed in an ANOVA, and lateral measures were analyzed in a non-parametric Kendall's test (main effect Condition, interaction Condition × Pre-Post measurement), and a non-parametric Wilcoxon's test (main effect Pre-Post measurement). In case of a significant main effect of Condition, post-hoc tests were carried out to test for differences between Condition pairs. In case of an interaction between Condition and Pre-Post measurement, post-hoc tests were carried out to test for a main Pre-Post measurement effect within each Condition, and to test for a main Condition effect at Pre-measurement and Post-measurement.

To determine at which locations along the ride driving behavior differed depending on the instruction on the second sign (research question 2), mean values of the longitudinal and lateral measures for each of the ten 250-meter segments were entered in an analysis with within-subjects factor Condition (3: 5-condition, 10-condition, 15-condition). Longitudinal measures were analyzed in an ANOVA, and lateral measures were analyzed in a non-parametric Kendall's test. In case of a main effect of Condition, post-hoc tests were carried out to test for differences between Condition pairs.

A square-root transformation was applied to the SD of speed and the SD of longitudinal acceleration/deceleration to correct for deviations of normality. For all analyses, P-value was set at 0.05. ANOVA's were corrected for deviations from sphericity (Greenhouse-Geisser epsilon correction). The corrected F- and probability values and the uncorrected degrees of freedom are reported.

6 RESULTS

This section is supported by three different tables. Table 1 displays a summary of statistical test results for longitudinal and lateral control measurements in response to the first and the second reroute sign. Table 2 gives a summary of statistical results for tests of Condition differences on longitudinal and lateral control measurements along the ride, for segments of 250 meters. Table 3 displays means for each of the longitudinal and lateral control measurements along the ride.

TABLE 1 Statistical Test Results for Longitudinal and Lateral Control Measurements in Response to the First and the Second Reroute Sign

	Sign 1		Sign 2	
Longitudinal Control				
	F	**p**	**F**	**P**
Speed				
Condition	F (2, 58) < 1	.44	F (2,58) = 1.4	.25
Pre-post	F (1, 29) < 1	.58	F (1, 29) = 8.8	.006
Condition × Pre-post	F (2, 58) = 1.7	.20	F (2, 58) = 2.8	.07
SD Speed				
Condition	F (2, 58) < 1	.87	F (2, 58) < 1	.64
Pre-post	F (1, 29) < 1	.83	F (1, 29) < 1	.37
Condition × Pre-post	F (2, 58) < 1	.70	F (2, 58) < 1	.67
Longitudinal Acceleration				
Condition	F(2,58) = 1.6	.22	F(2,58) = 2.7	.08
Pre-post	F(1, 29) = 25.4	<.0005	F(1, 29) = 10.3	.003
Condition × Pre-post	F(2, 58) < 1	.83	F(2, 58) = 1.4	.26
SD Longitudinal Acceleration				
Condition	F(2,58) < 1	.55	F(2,58) < 1	.82
Pre-post	F(1, 29) < 1	.88	F(1, 29) < 1	.74
Condition × Pre-post	F(2, 58) < 1	.72	F(2, 58) = 3.1	.05
Lateral Control				
	Kendall's W / Wilcoxon's Z	**p**	**Kendall's W / Wilcoxon's Z**	**P**
Lane switches				
Condition	W = .07	.138	W = .05	.22
Pre-post	Z = -1.726	.08	Z = -2.5	.01
Condition × Pre-post	W = .041	.29	W = .009	.76
Time on left lane				
Condition	W = .065	.14	W = .03	.41
Pre-post	Z = -0.022	.98	Z = -3.1	.002
Condition × Pre-post	W = .020	.55	W = .003	.90

TABLE 2 Statistical Test Results of Condition Differences on Longitudinal and Lateral Control Measurements Along the Ride for 250 Meter-Segments

		Longitudinal Control								**Lateral Control**	
		Speed		**SD Speed**		**Acceleration**		**SD Acceleration**		**Time on left lane**	
Distance to exit	Effect	F / t	p-value	F / t	p-value	F / t	p-value	F / t	p-value	Kendall's W/ Wilcoxon's Z	p-value
2500	Condition	F < 1	.37	F = 1.1	.32	F = 1.6	.21	F < 1	.72	W = .04	.27
2250	Condition	F = 1.3	.28	F < 1	.93	F < 1	.68	F < 1	.88	W = .06	.15
Sign 1 (for all Conditions)											
2000	Condition	F < 1	.75	F < 1	.74	F = 1.4	.25	F = 1.1	.33	W = .09	.06
1750	Condition	F = 7.2	.003	F = 2.2	.13	F = 17.5	<.0005	F = 4.8	.01	W = .11	.04
	5 - 10	t = 1.1	.29			t = 0.11	.92	t = 0.57	.57	Z = 0.51	.61
	5 - 15	t = 3.2	.003			t = 4.5	<.0005	t = 2.4	.02	Z = 1.8	.07
	10 - 15	t = 2.6	.01			t = 5.1	<.0005	t = 2.6	.02	Z = 1.0	.31
Sign 2 for Condition-15											
1500	Condition	F = 11.4	<.0005	F = 4.4	.03	F = 1.9	.16	F = 2.0	.15	W = .24	.001
	5 - 10	t = 2.2	.04	t = 1.2	.24					Z = 0.52	.61
	5 - 15	t =4.5	<.0005	t = 4.9	<.0005					Z = 3.1	.002
	10 - 15	t =2.7	.01	t = 1.4	.18					Z =2.9	.004
1250	Condition	F = 5.7	.006	F = 5.9	.01	F = 3.4	.05	F = 9.6	<.0005	W = .05	.23
	5 - 10	t = 3.1	.005	t = 3.1	.004	t = 0.81	.43	t =3.9	.001		
	5 - 15	t = 3.0	.006	t = 3.1	.005	t = 2.2	.04	t = 4.0	<.0005		
	10 - 15	t = .12	.86	t = 0.08	.94	t = 2.3	.03	t = 0.16	.87		
Sign 2 for Condition-10											
1000	Condition	F = 5.0	.010	F < 1	.63	F = 1.3	.29	F = 2.2	.12	W = .07	.12
	5 - 10	t =3.0	.006								
	5 - 15	t = 2.4	.02								
	10 - 15	t = 0.68	.51								
750	Condition	F < 1	.841	F = 2.5	.09	F = 10.5	<.0005	F = 1.1	.35	W = .02	.56
	5 - 10					t = 3.5	.001				
	5 - 15					t = 4.5	<.0005				
	10 - 15					t = .41	.69				
Sign 2 for Condition-5											
500	Condition	F = 2.7	.09	F< 1	.50	F < 1	.69	F < 1	.47	W = .02	.59
250	Condition	F = 2.1	.14	F = 1.5	.24	F < 1	.49	F < 1	.42	W = .009	.77

TABLE 3 Means of Each of the Longitudinal and Lateral Control Measurements Along the Ride, for 250 Meter-Segments

	Longitudinal Control												**Lateral Control**					
	Speed			**SD Speed**			**Acceleration**			**SD Acceleration**			**Time on left lane**			**Number of lane changes**		
	Condition			Condition			Condition			Condition			Condition			Condition		
Distance to exit	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
2500	110.7	110.7	114.6	2.8	3.9	2.4	0.11	-0.65	-0.24	1.16	1.47	1.38	69.4	50.8	62.5	0.17	0.17	0.23
2250	105.9	100.9	107.4	3.6	3.9	3.2	-0.62	-0.36	-0.64	1.30	1.17	1.11	66.1	35.8	52.2	0.07	0.17	0.07
Sign 1 (for all conditions)																		
2000	104.8	102.7	105.0	3.5	3.3	3.0	0.73	1.00	0.46	1.22	0.97	1.05	61.0	37.2	55.8	0.27	0.23	0.10
1750	**111.7**	**109.0**	**100.5**	3.0	2.8	4.3	**1.09**	**1.12**	**-0.74**	**0.97**	**0.87**	**1.80**	**65.0**	**58.5**	**50.3**	0.13	0.27	0.23
Sign 2 for Condition-15																		
1500	**115.4**	**108.1**	**98.8**	**1.9**	**3.9**	**4.3**	0.33	-0.27	0.49	0.87	1.45	1.50	**73.7**	**64.7**	**36.4**	0.17	0.23	0.37
1250	**112.6**	**99.8**	**100.6**	**1.7**	**3.9**	**3.9**	**-0.19**	**-0.54**	**0.52**	**0.71**	**1.66**	**1.72**	66.2	56.1	46.8	0.17	0.07	0.17
Sign 2 for Condition-10																		
1000	**107.2**	**96.6**	**99.1**	3.3	3.8	3.6	-0.63	-0.09	-0.56	1.17	1.25	1.58	61.1	44.7	41.9	0.13	0.27	0.23
750	98.5	96.7	97.0	3.7	3.4	2.4	**-1.04**	**0.19**	**0.33**	1.32	1.31	1.04	40.9	31.3	37.1	0.13	0.23	0.13
Sign 2 for Condition-5																		
500	90.4	95.3	98.4	4.6	3.9	3.9	-0.60	-0.32	-0.28	1.87	1.84	1.47	27.9	25.3	40.0	0.27	0.07	0.13
250	82.5	88.8	88.1	6.8	4.5	5.1	-0.62	-0.86	-1.12	2.34	1.72	1.80	21.4	16.2	24.6	0.20	0.13	0.17

NOTE Distance to exit: values represent the start (meters from exit) of 250 meter-segments; mean values are calculated for 250 meter-segments
Statistical significant condition differences are indicated in bold

For the first sign, following our expectations, there were no differences between the three conditions, as reflected by the absence of main effects of Condition or interactions between Condition and Pre-Post measurement for any of the driving parameters. The results showed deceleration of speed when the first sign was approached that differed significantly from speed acceleration after passing the sign, as reflected by a main Pre-Post measurement effect on acceleration.

In sum, the first (announcement) sign had an effect on longitudinal control (i.e. deceleration followed by acceleration) that was similar for the three conditions. The absence of any differences between the three conditions in response to the first sign serves as support for the reliability of our results as these signs were similar for all three conditions and therefore no differences were expected.

For the second sign, there were effects on longitudinal control measurements of speed and acceleration, and lateral control measurements of lane switches and time on the left lane, which will be described more in detail now. The pre-post difference in speed was largest for the 5-condition and decreased in the conditions where the second sign was presented earlier during the route; in the 10-condition, and even more in the 15-condition. Although the interaction between Condition and Pre-Post measurement was only marginally significant ($p = .07$), the linear pattern of speed decrease between the three conditions was confirmed by a significant linear interaction contrast ($F(1, 29) = 5.5$, $p = .03$) in the absence of a quadratic interaction contrast ($F(1, 29) < 1$, $p = .53$). Posthoc comparisons showed a significant decrease in speed only in the 5-condition ($t(29) = 3.8$, $p = .001$; 10-condition: $t(29) = 1.3$, $p = .19$; 15-condition: $t(29) = .81$, $p = .42$), no differences in speed between the three conditions on the pre-measurement ($F(2, 58) < 1$, $p = .83$), and a marginally significant difference on the post-measurement ($F(2, 58) = 3.1$, $p = .06$). Similar to the first sign, there was a pattern of longitudinal deceleration when the sign was approached, followed by a decrease of deceleration after passing the sign. This decrease of deceleration resulted in post-measurement acceleration only in the 15-condition, probably due to the larger distance between the second sign and the exit in this condition relative to the other two conditions. The size of the decrease of deceleration was similar in each condition, as reflected by a main Pre-Post measurement effect on acceleration in the absence of an interaction with Condition. In addition to this Pre-Post decrease of deceleration in every condition, the SD of acceleration in the 10-condition and the 15-condition decreased whereas it increased in the 5-condition, leading to an interaction between Condition and Pre-Post measurement. This pattern indicates that the smoothness in terms of acceleration or deceleration increased in the 10-condition and the 15-condition, whereas it decreased in the 5-condition when passing the second sign. However, posthoc comparisons showed no difference in SD between the three conditions for the pre-measurement ($F(2, 58) < 1$, $p = .37$) or post-measurement ($F(2, 58) = 1.3$, $p = .29$), and more important, there were no significant changes within any of the conditions (5: $t(29) = 1.6$, $p = .11$; 10: $t(29) = 1.6$, $p = .12$; 15: $t(29) = .97$, $p = .34$).

Regarding lateral control, in response to the second sign there was an increase in lane switches to the right lane that was similar in the three conditions, as reflected by a main Pre-Post measurement effect but no interaction between Condition and Pre-Post measurement for the parameters of lane switches and time spend on the left lane. A third lateral measure that was examined was the distance before the exit when the last lane switch to the right was made. Only drivers that made at least one lane switch were included in this analysis ($n = 25$). Although the pattern of means followed our expectation that on average drivers moved to the right lane sooner when the second (instruction) sign was presented earlier during the ride (5: 606 meters, 10: 725 meters, 15: 848 meters), there was no significant difference between the three conditions (F(2, 48) = 1.2, p = .32).

In sum, the second (instruction) sign had an effect on longitudinal control (i.e. speed reduction, deceleration followed by decreased deceleration) as well as lateral control (i.e. increased number of lane switches to the right lane). The effect on speed and the SD of acceleration differed depending on the instructed distance between the sign and the exit. That is, the relatively late warning for drivers that they were approaching the exit in the 5-condition resulted in a larger speed decrease relative to the other two conditions and in an increase of the SD of acceleration rather than a decrease, suggesting a more abrupt speed decrease.

As can be derived from Tables 2 and 3, there were no significant differences between the three conditions between 2500 and 1750 meters before the exit, when the first (announcement) sign was being approached and passed. This serves as support for the reliability of our results as these signs were similar in the three conditions and therefore no differences were expected. In addition, there were no condition differences during the last 500 meters before the exit. Although these 500 meters contained the 250 meter segment immediately after passing the second sign in the 5-condition, these 500 meters moreover represented the approach of the exit similar for every condition which can explain the absence of any condition differences. In general, following our expectations, condition differences occurred around those distances when the second (instruction) signs were presented. These condition differences will now be described in more detail.

Between 1750 and 1500 meters, in approaching the second sign in the 15-condition, there was a difference between the 15-condition on the one hand and the other two conditions on the other hand, on longitudinal measures of speed, acceleration, and the standard deviation of acceleration as well as on the lateral measure of time on the left/right lane. More specifically, in the 15-condition speed was lower, there was a deceleration (versus an acceleration in the other two conditions), and the SD of deceleration was higher relative to the other two conditions. In addition, time on the left lane was lower in the 15-condition than in the 5-condition (p = .07), with the 10-condition in between.

Between 1500 and 1250 meters, immediately after passing the second sign in the 15-condition, speed in the 15-condition was lower and the SD of speed was higher than in the 5-condition, with the 10-condition in between. In addition, time on the left lane was still lower in the 15-condition than in the 5-condition and the 10-condition.

In sum, these changes in driving behavior for the 15-condition relative to the other two conditions between 1750 and 1250 meters before the exit are in line with the occurrence of an additional event (i.e. instruction sign) only in this condition.

Between 1250 and 1000 meters, in approaching the second sign in the 10-condition, there were condition differences only for longitudinal parameters. That is, speed was lower in the 10-condition than in the other two conditions. Interestingly, the SD of both speed and the longitudinal acceleration were lowest in the 5-condition which suggests that the smoothness of speed and acceleration control was highest in this condition. The absence of any additional instruction sign after drivers passed the announcement sign only in the 5-condition seems responsible for this relative increased smoothness of control. That is, leaving drivers “without disturbance” for a longer time apparently can lead to a more balanced state of driving. Finally, speed acceleration in the 15-condition was higher than in the other two conditions which can be explained from the second sign at the start of the previous segment instructing drivers that they were far enough away still from the exit, thus allowing acceleration.

Between 1000 and 750 meters, immediately after passing the second sign in the 10-condition, speed in the 5-condition was significantly higher than in the 10-condition and the 15-condition. Again, this probably directly results from the absence of additional instruction up to this point in the 5-condition.

In sum, the changes in driving behavior between 1250 and 750 meters again occurred in response to the second sign that was passed, now in the 10-condition, as well as to the second sign passed earlier, in the 15-condition, relative to the other two conditions. In addition, the lack of an instruction sign also had an effect on driving behavior, in the 5-condition relative to the other two conditions.

Finally, between 750 and 500 meters before the exit, driving behavior was affected by the approaching of the second sign in the 5-condition, as there was a strong deceleration in the 5-condition that differed significantly from an acceleration in the 10-condition and the 15-condition. This is in line with the earlier noted increased speed in this condition resulting from lack of instruction.

7 DISCUSSION

The system of sequential advanced guide signing studied here confronts the driver with a series of three consecutive signs with the first two aimed at preparing the driver's behavior to the problem situation at hand. The first *announcement* sign, located at 2km ahead of the target exit in each of the three conditions serves to raise awareness, not to induce immediate behavioral changes in the driver. In line with this, only the way in which subjects handled speed was affected: in approaching the sign, they slightly decelerated while they accelerated again once passed by. Possibly, deceleration was due to the instruction of subjects to read the signs, requiring them to slow down when the sign came in sight.

The second *instruction* sign, located at 500m, 1000m, or 1500m ahead of the target exit, depending on condition, is the key-stimulus in terms of having the driver adapt his vehicle movements to the upcoming situation in a safe and smooth manner. Indeed, this sign functioned as an action trigger. Firstly, it influenced longitudinal control as speed and the degree of deceleration decreased after passing the sign relative to the approach of it. Secondly, it influenced lateral control as the number of switches to the right lane increased after passing the sign relative to the approach of it .

Interestingly, the effect on mean speed and the SD of acceleration/deceleration differed in function of the instruction sign's longitudinal location. That is, the relatively late warning for drivers that they were approaching the exit in the 5-condition resulted in a larger speed decrease relative to the other two conditions, and in an increase of the SD of deceleration rather than a decrease, suggesting a more abrupt speed decrease.

By synchronizing each of the ten within-condition test drive segments across the three conditions and going through the three synchronized test drives chronologically, we were able to determine that driving behavior between conditions differed for the first time at a distance of 1750 to 1250 meters before the exit. More in detail, the 15-condition deviated from the 10 and 5-conditions with lower speed, higher SD of deceleration and decreased time on the left lane. This can be explained by the second (instruction) sign presented at this location already only in the 15-condition, whereas it was presented at a further location in the 5 and 10-condition.

At a distance of 1250 to 750 meters ahead of the exit, between-condition driving behavior manifests a second series of differences with the most notorious ones being lower speed in the 10-condition vs. the 15 and 5-conditions, higher speed acceleration in the 15-condition vs. the 5 and 10-conditions and lower SD of both speed and acceleration in the 5-condition vs. the 10 and 15-conditions. The second (instruction) sign was presented at this location in the 10-condition which explains speed decrease in this condition. Speed acceleration in the 15-condition can be explained by the fact that the instruction sign passed in the previous section indicated that drivers were still far enough away from the exit. We assume the steadiness of mean speed and acceleration reflected by the lower SD in the 5-condition are due to the absence of any instruction sign, inducing an undisturbed driving style.

A final difference in driver behavior between conditions occurred between 750 and 500 meters before the exit. Here, drivers in the 5-condition showed a significantly stronger deceleration than in the 10 and 15-conditions, probably due to the second (instruction) sign that is presented then to these drivers.

8 CONCLUSION AND RECOMMENDATIONS

Three research questions were formulated at the beginning of the paper. As for the first question, the first *announcement* sign only affected longitudinal acceleration, which is in line with its function to raise driver's awareness. The second *instruction* sign had an effect on longitudinal (i.e., mean speed and SD for acceleration/deceleration) as well as lateral (i.e., number of lane switches to the right) driver behavior, which is in line with its function to influence the driver's vehicle conduct.

For the second research question, the instruction sign's effect on the drivers' vehicle maneuvering indeed varied in function of the sign's longitudinal distance from the target exit. Longitudinally, the largest and most abrupt speed decrease was found in the 5-condition. Laterally, the last switch to the right lane varied in function of the instruction sign's distance from the exit (i.e., 5-condition: 606 meters, 10-condition: 725 meters, 15-condition: 848 meters).

With respect to the third research question, we established how between-condition driver behavior differed and evolved along the test-ride with most prominent changes occurring at 1750-1250 meters before the exit for the 15-condition, at 1250-750 meters before the exit for the 10-condition and at 750-500 meters before the exit for the 5-condition, corresponding exactly with the location of the second (instruction) sign in each of the conditions.

Placing the instruction sign at 1500 meters away from the exit, makes the driver adjust both longitudinal and lateral management of the vehicle earlier than in the two other conditions. Since this avoids last-minute movements and speed adaptations it is often regarded safer and most recommendable. However, not everybody agrees on this. Finley et al. (*11*) for instance, suggest that it might be better both in terms of safety and traffic flow to access the right lane later, farther upstream.

Based on our results it can be concluded that locating the instruction sign at 500 meters before the target exit is not an advisable option since it induces an undisturbed driving style with too abrupt changes in the driver's longitudinal control of the vehicle just in front of the exit. When the instruction sign was located at 1000 meters away from the exit, adaptation of the driver's control over the vehicle showed no abrupt changes, evolved in a rather smooth manner, and resulted in a last switch to the right lane at a mean distance of 725 meters away from the exit. Therefore, in terms of Finley et al., 1000 meters before the exit appears to be the closest location that still induces safe driver behavior, which makes this the most optimal solution.

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