The Effects of Road Marking Patterns on Simulated Driving Speed and Lane Position

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Special thanks are due to Shinnosuke Usui, Ph.D., Hiroshi Nakai, Ph.D., Yuko Adachi, Ph.D., Shingo Moriizumi, Ph.D., Yasunori Kinosada, Ph.D., and Kenta Yamada for providing all of the educational resources and essential advice. The author is also thankful to West Nippon Expressway Co., Ltd., West Nippon Expressway Facilities Co., Ltd., and Hanshin Expressway R&D Co., Ltd. for providing information regarding current applications of road markings on highways. Lastly, the author would like to thank Kristianna Elysse Flores for revising English expressions.

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Table of Contents

List of Figures

List of Tables

Abstract

Although road markings have been installed on highways as perceptual countermeasures for speed reduction, little is known about the effects of road marking shape and interval on driving speed and lane position. An experiment with a driving simulator and questionnaires were conducted to explore the effects of road marking patterns on driving speed and lane position in association with drivers' subjective feelings, mental workload, and visual attention. Thirty-nine participants drove on a simulated two-lane rural road, which had road markings with different shapes and intervals at curves, and filled out the questionnaires. Road markings reduced both throttle value and mean speed before entering a curve though throttle and mean speed remained the same in a curve. Although marking shape did not affect participants' choice of speed, an alarming effect of the road markings was observed because the participants tended to drive slower with the road markings with a fixed interval than with those with converging intervals towards the travelling direction. A questionnaire on drivers' attention implied a possible use of road markings for drivers' lane position keeping, even though standard deviation of lane position was not fully investigated due to a floor effect. Further investigations on the effect of road markings in different situations are required to achieve the more fitting use of road markings.

Keywords: driving simulation, perceptual countermeasures, road markings, speeding, lane position

The Effects of Road Marking Patterns on Simulated Driving Speed and Lane Position

Why Speeding Matters

Speeding is a critical issue in traffic safety. Numbers of on-road studies have reported vehicle speed to be a major determinant of both accident and fatality rate (Gallaher, Sewell, Flint, Herndon, Graff, Fenner, & Hull, 1989; Friedman, Barach, & Richter, 2007; Friedman, Hedeker, & Richter, 2009; Ossiander & Cummings, 2002).

One of the major indicators of a potential crash is the time-to-collision (TTC), which is defined as "the time required for two vehicles to collide if they continue at their present speed and on the same path (Hawyard, 1972)." Because driving behavior is considered to be a series of routines composed of recognition, decision, and operation (Rumar, 1985), higher driving speeds lead to less spatial margin for drivers. Because the TTC for a vehicle is inversely proportional to the driving speed, potential crash risk becomes higher as the vehicle speed increases. In addition, crash impacts vary in proportion to the square of the speed.

$$K(t) = \frac{1}{2}mv^2 \quad \text{...} \quad (1)$$

where: m = mass of object

v = velocity of object

$K(t)$ = kinetic energy

As Aarts and van Schagen (2006) revealed exponential relations between driving speed and crash rate as well as driving speed and fatality, it is important to reduce vehicle speed not only to prevent accidents, but also to reduce accident severity.

Development of Perceptual Countermeasures

A variety of traffic calming measures have been installed on roads for the sake of reducing vehicle speed. For example, static engineering measures include the use of radar speed signs whereas dynamic measures cover distribution of public safety personnel (Rothenberg, Benavente, & Swift, 2004). These types of measures, however, are not widely applicable because static measures tend to require a high cost to install while dynamic measures need a large amount of local human resource for enforcement. In addition, drivers' behavioral adaptation to these measures results in a decline in the effects (Lewis-Evans & Charlton, 2006; Rudin-Brown & Jamson, 2013).

Perceptual countermeasures have been developed since they have a possibility to overcome behavioral adaptation as long as they work implicitly. As Hills (1980) reported that visual information occupies over 90% of all the information processed by drivers, visual information is essential for driving. Gibson (1979) introduced the concept of optic flow, defining the term as "the pattern of apparent motion of objects, surfaces, and edges in a visual scene caused by the relative motion between an observer (an eye or a camera) and the scene." The concept of optic flow indicated that drivers' feeling of speed relies more on peripheral vision than on foveal vision since the length of a vector at the same time period is bigger in the peripheral visual field than in the foveal visual field.

Researchers have been creating models in order to reveal a driver's behavior. The earliest model of driver's behavior is the Zero Risk Model (ZRM) proposed by Näätänen and Summala (1974). In the ZRM, the researchers described that driver's subjective risk remains zero unless some events make their risk cross over the threshold to change their risk-related behaviors. Wilde (1982) described in his Risk Homeostasis Theory (RHT) that drivers aim to experience a certain level of risk by compensation (e.g., speed reduction). Based on the RHT, Fuller (2005) proposed the Risk Allostasis Theory (RAT), in which drivers maintain their feeling of risk within a certain range by compensation.

Drivers select their speeds based on their perception of the environments they drive through (Misaghi & Hassan, 2005). Although there are some arguments regarding which models are the most legitimate, these models are all in agreement in that higher perceived risk, which is often underestimated, eventually leads to safer behavior and vice versa. Perceptual countermeasures mainly intend to increase drivers' perception of risk by modifying roadside scenery and placing road markings on roads. Road markings, in particular, are used more frequently than roadside scenery modification because of their low installation costs. Although speedometers enable drivers to watch driving speed, speed perception still plays a significant role in terms of traffic safety because drivers who especially tend to indulge in risky driving behavior (e.g., sensation seekers) may be less likely to monitor their speeds.

Effects of Road Markings as Perceptual Countermeasures

Speed reduction. Various patterns of road markings have been tested as perceptual countermeasures (Elvik, Vaa, Erke, & Sorensen, 2009; Gates, Qin, & Noyce, 2008; Kozaki & Fukui, 1991; Retting & Farmer, 1998; Retting, McGee, & Farmer, 2000; Voigt & Kuchangi, 2009).

Denton (1980) conducted an experiment presenting wide transverse bars with different rates of interval convergence and revealed a negative correlation between the volume of information presented per a unit of time and a driver's time perception. The researcher also found out significant speed reduction both in mean speed and 85th percentile speed, ranging 18.5% through 34.3% after the installation of wide transverse bars with converging intervals preceding a roundabout in Midlothian, Scotland. Although the author concluded that the feeling of acceleration contributed the speed reduction, this study was one of the numbers of studies that were not able to distinguish the effect of longitudinal marking density from the effect of the illusion of acceleration.

The earliest application of chevron markings took place in Japan, where the combination of converging sets of chevron markings and constant parallelogram edge lines were introduced on a bridge across the Yodo River in Osaka (Drakopoulos & Vergou, 2003). Although speed-related data were not available, this reduced the number of accidents from 10 in the previous year to 0 in the 6 months following the installation.

Drakopoulos and Vergou (2003) investigated vehicle speeds at a freeway-to-freeway exit ramp on I-94 in Milwaukee County, Wisconsin before and after the installation of converging sets of chevron markings and constant parallelogram edge lines at the 195 m preceding sharp curves. The road marking introduced in this study was similar to those introduced on the bridge in Japan. After the installation, mean driving speed dropped 14 km/h compared to a comparison site. Reduction in the number of accidents was also suggested.

Takada (1997) assessed the effects of parallelogram edge lines in Shiga, Japan. In this study, introducing the road markings at curves resulted in 1.6-5.7 km/h reduction in mean speeds as well as 1.9-8.4 km/h reduction in 85th percentile speeds.

In 2008, the Metropolitan Expressway in Japan introduced a series of egg-shaped markings called “Optical Dots” on a highway in Saitama Prefecture as potential measures for speed reduction. Although vehicles showed some degree of speed reduction (Han, Tamaki, Ono, Sasaki, Suda, & Ikeuchi, 2012), it is still questionable whether the Optical Dots are better than the other types of road markings in speed reduction.

In China, Liu, Zhu, Wang, Xia, and Sun (2009) used animated clips of a driver’s view, where edge line markings appeared at different frequencies (intervals), to find the most overrated driving speed between 8 Hz and 16 Hz and the decline of overrating speed with frequencies over 16 Hz. Participants underrated driving speed when marking frequency exceeded 32 Hz, presumably because of the flicker fusion phenomenon. Liu, Zhu, Wang, and Cheng (2013) evaluated the effect of marking frequency (interval) on vehicle speed on the Hangzhou–Ruili Expressway in China. The researchers compared driving speeds on two straight roadways that had yellow edge lines with different frequencies. Although the study found larger speed reduction in the higher frequency than in the lower frequency, it is questionable whether only marking frequency affected drivers' speed choice because the roadway with the higher frequency had smaller lateral clearance due to the juxtaposition of the edge lines, which may require drivers to put more effort to maintain lateral lane position.

Some studies have shown alarming effects of road markings, although perceptual countermeasures originally developed as devices that elicit the feeling of acceleration.

Jarvis and Jordan (1990) found that yellow transverse bars reduced the approach speeds towards the road markings, concluding that the road markings functioned as a large warning signal rather than creating the illusion of acceleration.

Godley, Fildes, Triggs, and Brown (1999) carried out an experiment using a driving simulator to evaluate effects of wide transverse bars and edge lines both with constant and with converging intervals. They found lower mean speed in wide transverse bars than in edge lines during the first 100 m of the markings. The researchers interpreted this as an alarming effect because wide transverse lines were bigger than the other. They did not reveal any significant difference in mean speed between the 2 types of marking intervals, concluding that the convergence of marking interval does not have an impact on drivers' choice of speed.

Katz (2007) compared the effects of peripheral transverse lines on highways in Syracuse, New York, in Flowood, Mississippi, and in Waller, Texas to reveal speed reduction effect at all of these sites. The degree of speed reduction, however, varied from site to site, showing the minimum speed reduction in Waller, Texas. Because the Waller site had a higher percentage of local drivers than the other sites, the author assumed that the road markings had some alarming effect.

Lane keeping. Road markings are also used to trying to maintain lane position by attracting drivers' eyes. Drivers are thought to scan the curvature before they enter a curve (Shinar, Mcdowell, & Rockwell, 1977). At curves, drivers tend to look at the apex of the inner division line while maintaining their lane position with their peripheral vision (Land & Lee, 1994). As for lane keeping behavior, Mourant and Rockwell (1970) revealed that peripheral vision plays a role to monitor lane position. On the other hand, Summala (1998) concluded that the foveal task load does not influence peripheral lane keeping performance, although attention requires foveal load in the visual field. For these reasons, narrow chevron may have a possibility to play a role of a lateral guide while driving whereas edge lines are believed to make lanes look narrower. Research on driver's visual attention, however, has not been done with multiple patterns of road markings.

Researchers have found the smaller standard deviation of lane position with narrow lane width than with wider lane width in both a simulated environment (Dijksterhuis, Brookhuis, & de Waard, 2011; Rosey, Auberlet, Moisan, & Dupré, 2009) and on roads (Rosey et al., 2009).

Furthermore, He, McCarley, and Kramer (2014) found a lower standard deviation of lane position in high workload condition than low workload condition by using an auditory working memory task. This result suggested a possibility to maintain lane position by presenting road markings that caused high workload to drivers. Because of this, workload assessments for road marking patterns are worth carrying out

Purpose of the Present Study

Evaluation of the effects of road marking patterns on driving speed and lane position in a controlled condition has a possibility to promote more fitting installation of pavement markings. Jamson, Pyne, and Carsten (1999) compared the effects of wide transverse bars, narrow transverse bars, and wide chevron markings with the Wundt illusion, which had the potential of giving the feeling of lane narrowing. Although all treatments caused 4.9-5.9 km/h of mean speed reduction, 85th speed showed the biggest decline with wide transverse bars. This result was in line with Gibson's idea of optic flow, which suggests that drivers feel their speeds with their peripheral vision.

Although it is important to establish optimal design of road markings in terms of not only traffic safety, but also economy, various types of pavement markings have been applied as traffic countermeasures without robust criteria because extremely limited numbers of studies have assessed the effects of various road marking patterns (e.g., shape and interval).

In Japan, the National Police Agency Department of Transportation (2014) recommends the use of "the most fitting" marking patterns "by considering the situations," yet it is unclear how to select "the most fitting" marking patterns. The West Nippon Expressway Company (NEXCO West Japan) and the Hanshin Expressway has installed parallelogram edge lines, wide chevrons, and narrow chevrons before and on hazardous curves based on "the experiences of the persons in charge" for the sake of reductions in driving speed as well as in lane position variance.

Because little is known about the effects of road marking shape and interval on driving speed and lane position, the purpose of the present study was to explore the effects of multiple types of road markings used in Japan on driving speed and lane position variance in a simulated environment. This study also aimed to investigate a driver's visual attentional pattern and subjective feelings as well as mental workload on each road marking.

If behavioral adaptation occurs at a conscious level, unobtrusive countermeasures have a possibility to overcome it. As an attempt to reveal drivers' psychological process, this experiment also investigated whether the road markings work as implicitly or explicitly by setting two conditions: Road markings with a constant interval and road markings with converging intervals towards the direction of travel. In this experiment, the fixed interval was set as the same as the minimum interval of the converging condition because most of the studies on marking intervals had a significant weakness in that they were not been able to distinguish the effect of longitudinal marking density from the effect of changing speed perception.

Hypothesis

If road markings work as an implicit device causing the illusion of acceleration rather than as an explicit warning object, drivers drive at a lower speed through the road markings with converging intervals than through those with a constant interval. If road markings work as an explicit warning sign rather than as an implicit device causing the feeling of acceleration, drivers drive at the same or lower speeds through the road markings with constant intervals than through those with converging intervals.

$$v_\alpha > v_\beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$v_\alpha \leq v_\beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where: v_α = driving speed through road markings with a constant interval

v_β = driving speed through road markings with converging intervals

Although alarming effect and the illusion of acceleration are not mutually exclusive, it is worth revealing which effect plays a larger role in speed reduction.

Method

Design

The present study was composed of 2 parts: a driving session and a questionnaire session.

Driving session. The experiment used a two-layer hierarchical research design composed of an experiment with a single factor and a 4 × 2 factorial research design for speed-related measures. The independent variable in the experiment with a single factor was the existence of road markings (*Control* and *Treatments*) whereas the 4 × 2 factorial research design had marking shape (*None*, *Parallelogram Edge Line*, *Wide Chevron*, *Narrow Chevron*, and *Optical Dots*) and their interval (*Constant* and *Convergent*) as independent variables. Participants went through each condition 4 times.

For standard deviation of lane position, marking shape (*None*, *Parallelogram Edge Line*, *Wide Chevron*, *Narrow Chevron*, and *Optical Dots*) was an independent variable.

All independent variables were within-subjects variables. The dependent variables were mean speed, throttle, and standard deviation of lane position (*SDLP*). Table 1 shows the locations of the independent variables.

Questionnaire session. For the CG Animation Questionnaire, marking shape (*None*, *Parallelogram Edge Line*, *Wide Chevron*, *Narrow Chevron*, and *Optical Dots*) was a within-subjects independent variable.

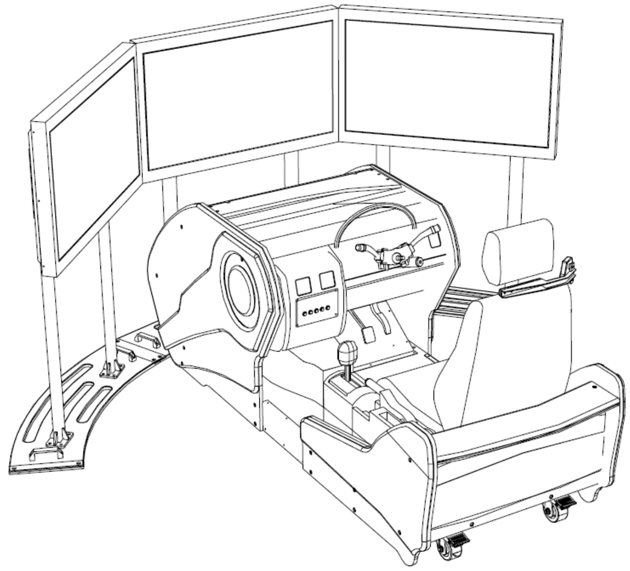
Participants

The data consisted of 39 participants, who had a valid Japanese driver’s license. Seven of them were female whereas the other 32 were male. They were 22.55 (*SD* = 5.08) years old and had been driving for 2.89 (*SD* = 4.95) years on average. Participants were voluntarily recruited through a website and the experiment took each participant about 1 hour, which was compensated by 1,000 Japanese yen.

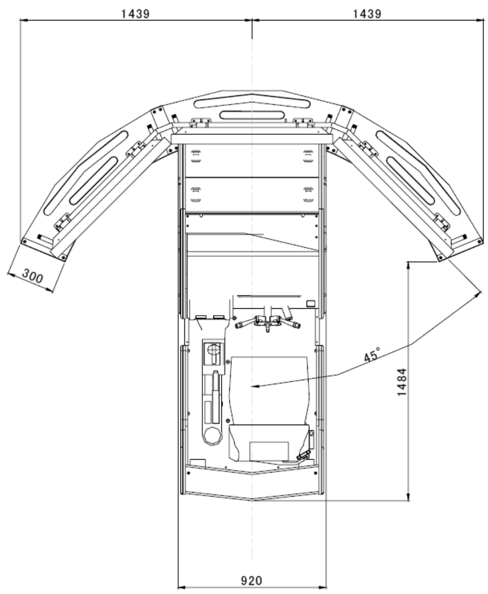
Materials

Driving simulator. UC-win/Road Ver. 9.0.3, a driving simulation software developed by FORUM 8 Co., Ltd., was used to present simulated driving environment and to store logs. A driving simulator made by SIMREX Corporation (Figure 1) was used to input participants' performance. Three displays made by LG Electronics Inc. (42LA6650) displayed simulated images with 1,920 × 1,080 pixel resolutions. Engine noise was presented through a speaker while the seat vibrated in response to engine speed. Participants drove a coupe (Figure 2).

Isometric view



Top view



Side view

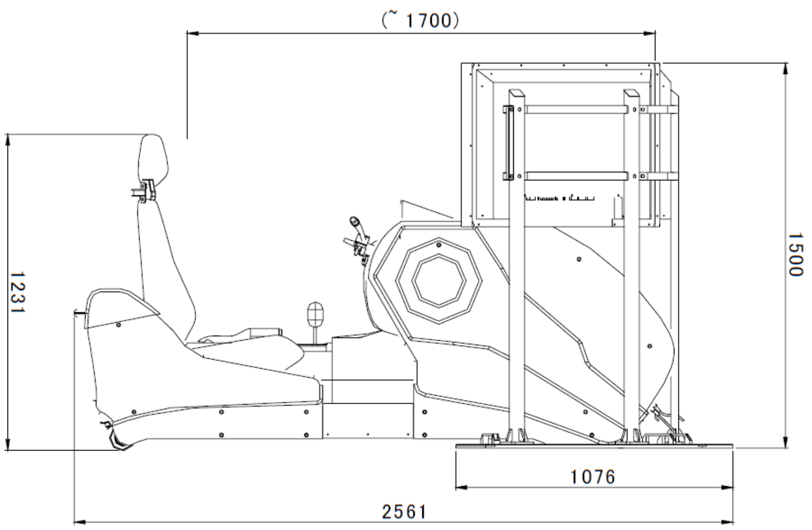


Figure 1. Dimensions of the driving simulator. Adapted from “UC-win/Road Driving Simulator (3ch Compatible) User's Manual,” by FORUM 8, 2010, p. 57. Copyright 2010 by FORUM 8.

Figure 2. A coupe used in the driving simulation.

Course. The driving course was created with and simulated in UC-win/Road. The course was a 36.266 km-long rural highway with two lanes on each side, consisting of a series of nine U-shaped blocks (Figure 3). Each block had four curves with the radius of 220 m. Although highways in Japan set 300 m as a minimum curve radius, the course in the present experiment had the radius of 220 m in a curve for the purpose of deliberately exploring the effects of the road markings. Located 10 m above the flat ground, each side of the road was separated with a guard rail with light poles on it at intervals of 40 m. Widths of road elements were 3.5m for a lane, 0.15m for a division line, 1.25m for the left shoulder, and 0.3m for the right shoulder. There were no buildings along the course. The opposite lanes had traffic flow running at 60 km/h at 7.2-second intervals.

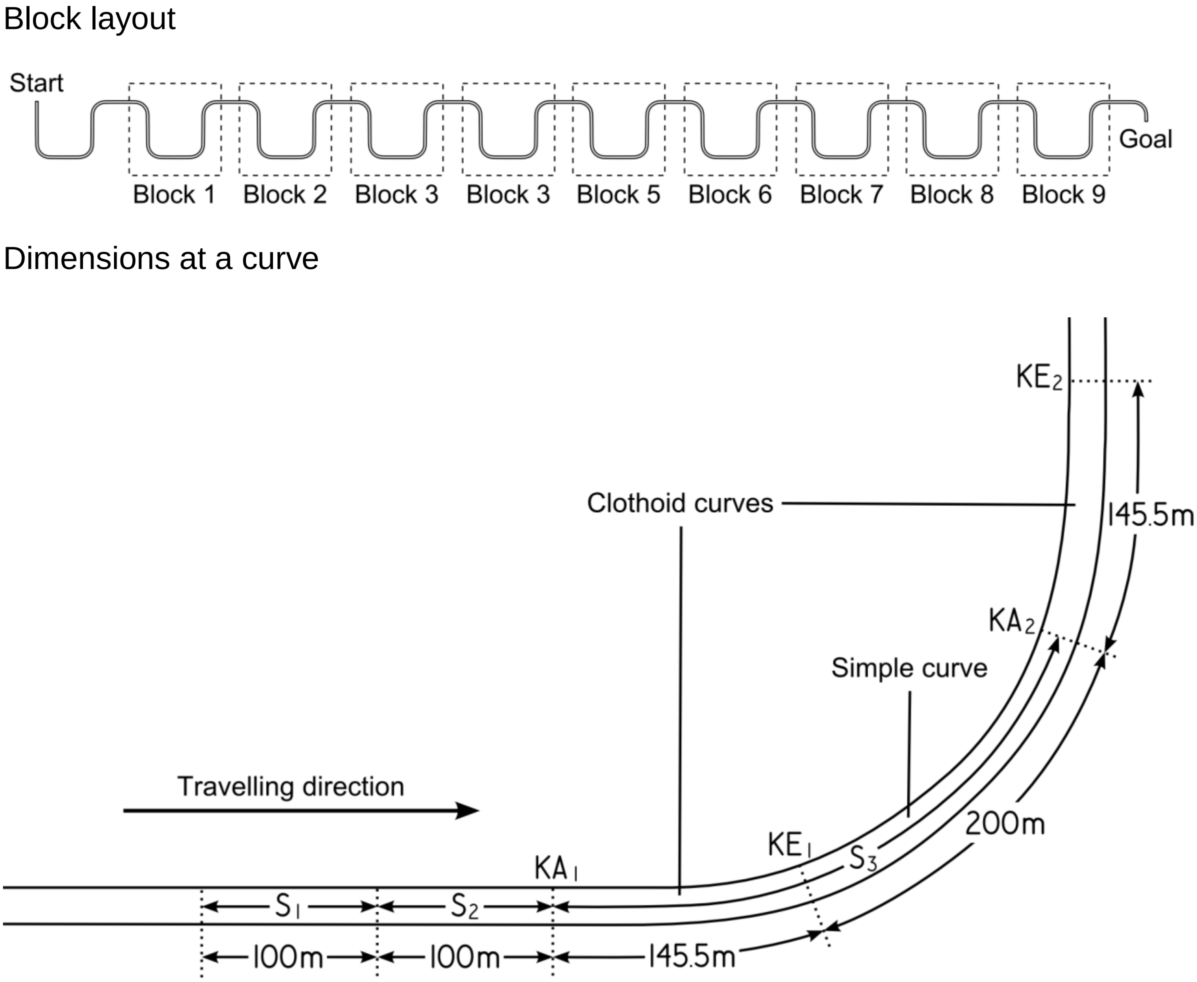


Figure 3. The course layout. KA = the beginning of a clothoid curve, KE = the end of a clothoid curve, S = section.

Road Markings. Four patterns of road markings, *Parallelogram Edge Line, Wide Chevron*, *Narrow Chevron*, and *Optical Dots*, were implemented (Figure 4). Each pattern of road markings was installed between 200 m prior to the beginning of the first clothoid curve and the end of a simple curve. The order of the road markings was counterbalanced using the ABBA method throughout the course (Table 1). The color of the road markings was white in accordance with the current policy of the National Police Agency of Japan (National Police Agency Department of Transportation, 2014). Table 2 shows the locations of a series of the road markings at a site and Figure 5 exhibits screenshots of the driving courses. The marking interval in the *Convergent* condition was decreased in stages based on applications on roads.

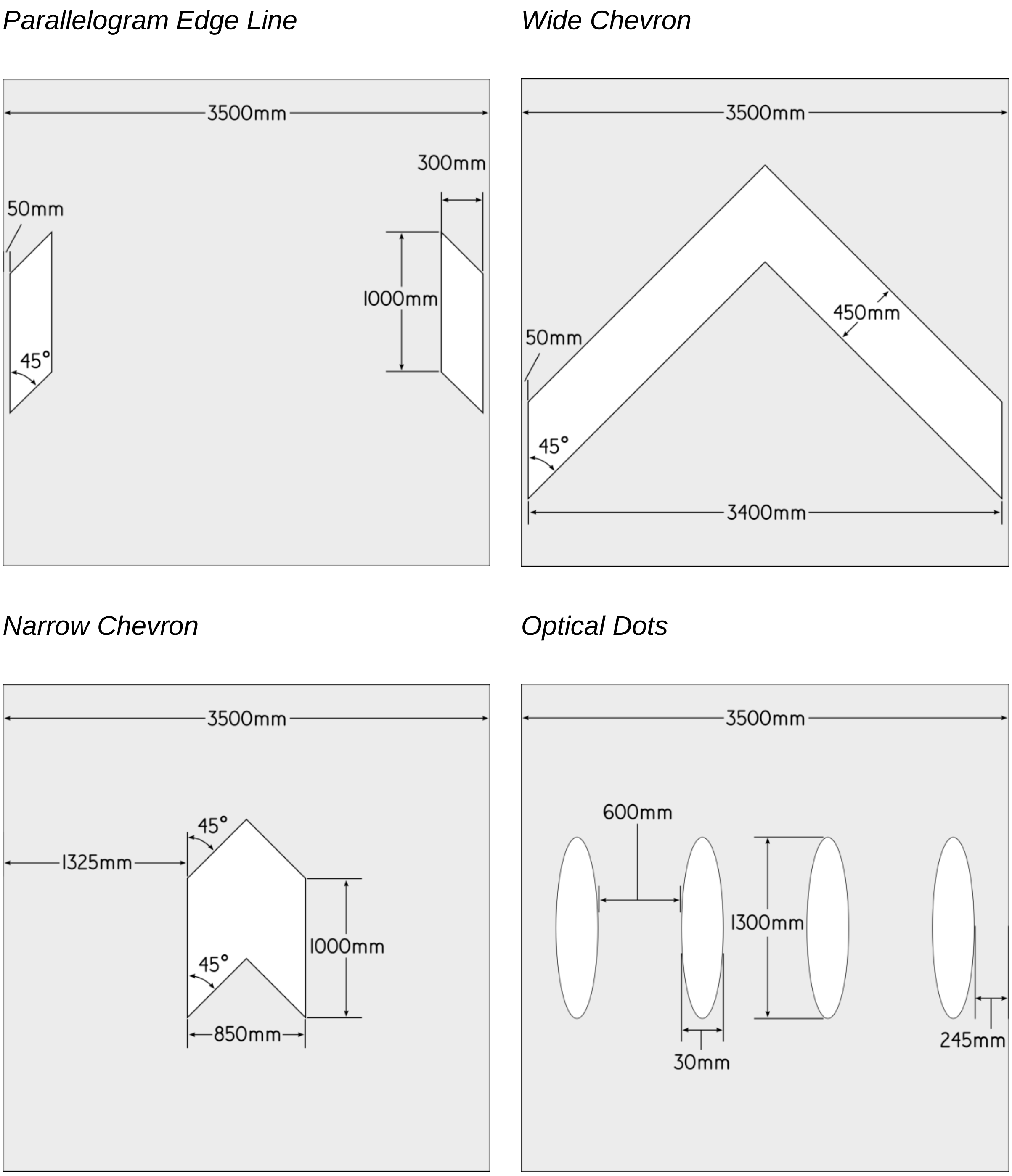


Figure 4. Dimensions of the pavement markings. The upper side of each pattern is the direction of travel.

Table 1

Counterbalanced Curve Profiles of the Driving Course

	Curve[a]					Marking	
Block	Direction	KA_1	KE_1	KA_2	KE_2	Pattern	Interval
1	Right	3398	3543.5	3743.5	3889	*None*	-
	Left	4296	4441.5	4641.5	4787	*Parallelogram Edge Line*	*Constant*
	Left	5194	5339.5	5539.5	5685	*Optical Dots*	*Convergent*
	Right	6092	6237.5	6437.5	6583	*Wide Chevron*	*Constant*
2	Right	6990	7135.5	7335.5	7481	*Narrow Chevron*	*Convergent*
	Left	7888	8033.5	8233.5	8379	*Parallelogram Edge Line*	*Convergent*
	Left	8787	8932.5	9132.5	9278	*Optical Dots*	*Constant*
	Right	9685	9830.5	10030.5	10176	*Wide Chevron*	*Convergent*
3	Right	10583	10728.5	10928.5	11074	*Narrow Chevron*	*Constant*
	Left	11481	11626.5	11826.5	11972	*Narrow Chevron*	*Constant*
	Left	12379	12524.5	12724.5	12870	*Wide Chevron*	*Convergent*
	Right	13277	13422.5	13622.5	13768	*Optical Dots*	*Constant*
4	Right	14175	14320.5	14520.5	14666	*Parallelogram Edge Line*	*Convergent*
	Left	15073	15218.5	15418.5	15564	*Narrow Chevron*	*Convergent*
	Left	15971	16116.5	16316.5	16462	*Wide Chevron*	*Constant*
	Right	16870	17015.5	17215.5	17361	*Optical Dots*	*Convergent*
5	Right	17768	17913.5	18113.5	18259	*Parallelogram Edge Line*	*Constant*
	Left	18666	18811.5	19011.5	19157	*None*	-
	Left	19564	19709.5	19909.5	20055	*None*	-
	Right	20462	20607.5	20807.5	20953	*Parallelogram Edge Line*	*Constant*
6	Right	21360	21505.5	21705.5	21851	*Optical Dots*	*Convergent*
	Left	22258	22403.5	22603.5	22749	*Wide Chevron*	*Constant*
	Left	23156	23301.5	23501.5	23647	*Narrow Chevron*	*Convergent*
	Right	24054	24199.5	24399.5	24545	*Parallelogram Edge Line*	*Convergent*
7	Right	24952	25097.5	25297.5	25443	*Optical Dots*	*Constant*
	Left	25850	25995.5	26195.5	26341	*Wide Chevron*	*Convergent*
	Left	26749	26894.5	27094.5	27240	*Narrow Chevron*	*Constant*
	Right	27647	27792.5	27992.5	28138	*Narrow Chevron*	*Constant*
8	Right	28545	28690.5	28890.5	29036	*Wide Chevron*	*Convergent*
	Left	29443	29588.5	29788.5	29934	*Optical Dots*	*Constant*
	Left	30341	30486.5	30686.5	30832	*Parallelogram Edge Line*	*Convergent*
	Right	31239	31384.5	31584.5	31730	*Narrow Chevron*	*Convergent*
9	Right	32137	32282.5	32482.5	32628	*Wide Chevron*	*Constant*
	Left	33035	33180.5	33380.5	33526	*Optical Dots*	*Convergent*
	Left	33934	34079.5	34279.5	34425	*Parallelogram Edge Line*	*Constant*
	Right	34832	34977.5	35177.5	35323	*None*	-

Note. KA = the beginning of a clothoid curve, KE = the end of a clothoid curve.

[a] The units are in m.

Table 2

Locations of a Series of the Road Markings

Condition	Group	Interval [a]	Number of markings	Distance to the first marking from the beginning of a clothoid curve [a]
Constant				
	1	3	182	0
Convergent				
	1	9	6	0
	2	7	7	54
	3	5	10	103
	4	3	131	153

Note. [a] The units are in m.

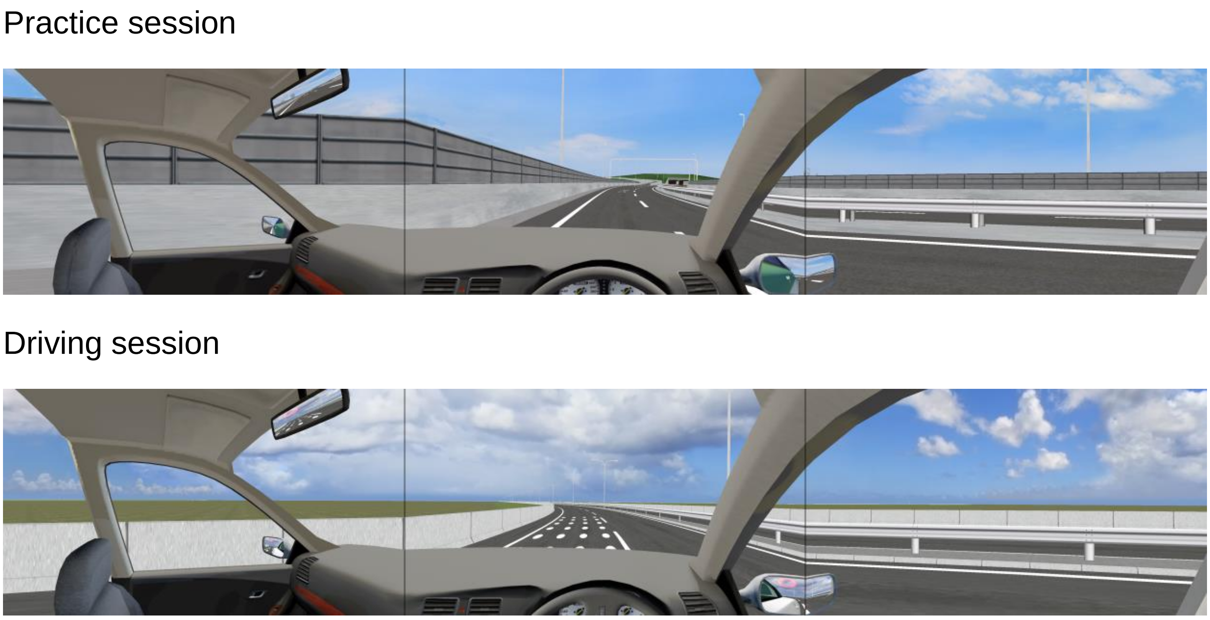


Figure 5. Screenshots of the driving courses.

CG Animation Questionnaire. A modified version of the CG Animation Questionnaire, originally developed by Adachi, Fujii, Tamagawa, Iwasato, Yamada, and Nakamura (2009) in order to assess subjective feelings for “sequence designs” on a tunnel wall, was used in this study to reveal participants’ subjective feelings against the road markings. The present questionnaire consisted of 7 scales: *Feel of Danger*, *Feeling of Speeding*, *Eyes on the Road*, *Driving Difficulty*, and *Difficulty of Grasping Distance*. Each scale was evaluated on the seven-point Likert scale (“1 – Strongly disagree,” “2 – Disagree,” “3 – Disagree somewhat,” “4 – Neither agree nor disagree,” “5 – Agree somewhat,” “6 - Agree,” “7 – Strongly agree”). Because mental workload, effort, and task difficulty are strongly correlated (Mulder, 1986; Rudin-Brown & Jamson, 2013), *Driving Difficulty* was considered as mental workload.

Participants assessed the scales while watching each video clip displaying driver’s view of driving at 80 km/h through a right curve section with each pattern of road marking on it (Figure 6). The questionnaire was presented using a laptop computer.

Grid Image Questionnaire. Five static images of right simple curve sections from the driver’s view with 1,800 (60 horizontally × 30 vertically) grids (Figure 7) were used to report the areas where participants specifically looked at or took care of during the driving session by circling the areas with any sizes.

Each image in this questionnaire had each pattern of road markings. The order of the images was counterbalanced between participants.

Figure 6. A screenshot of a clip presented in the CG Animation Questionnaire.

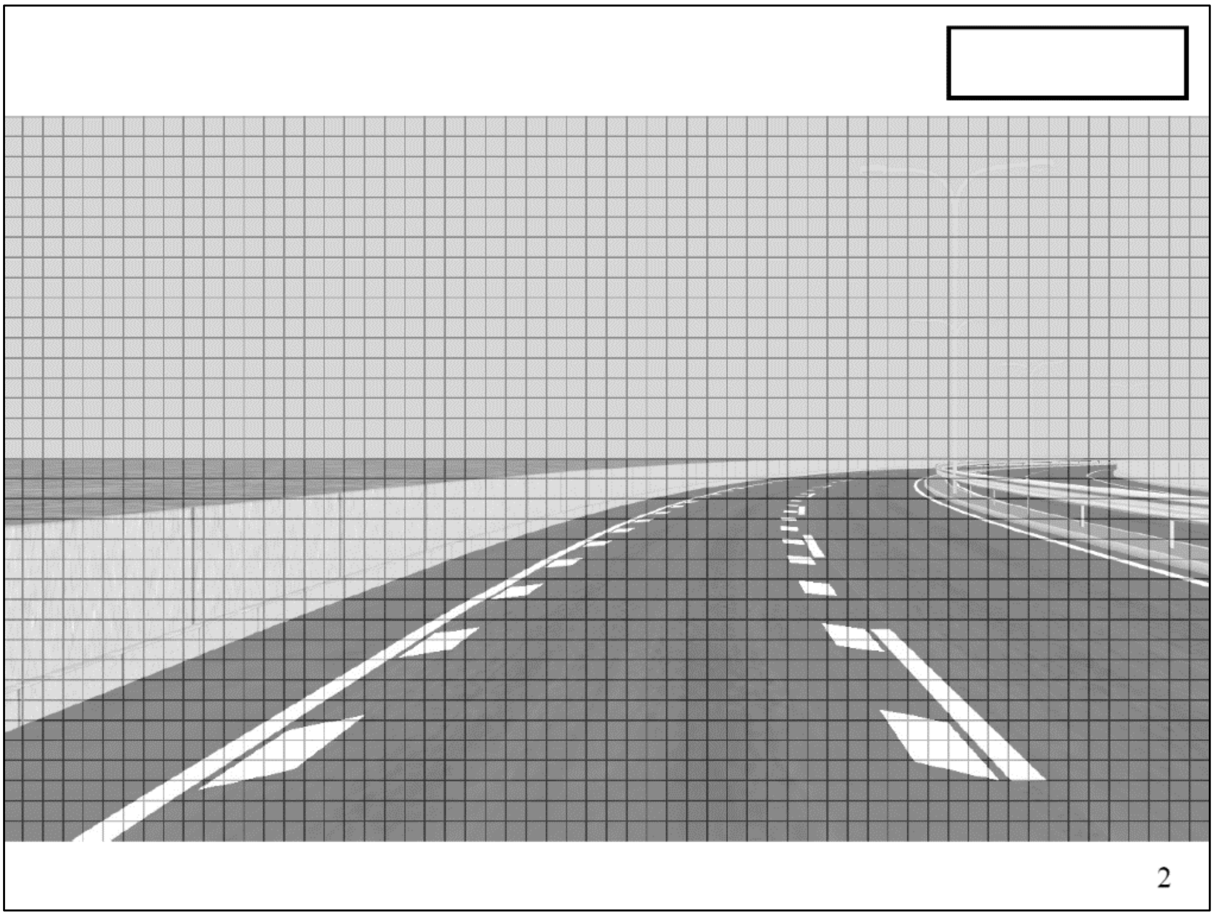


Figure 7. One of the five sheets in the Grid Image Questionnaire.

Procedure

The experiment was conducted in Room M308 at Osaka University School of Human Sciences Main Building from Oct. 23, 2014 through Nov. 15, 2014.

Informed consent. Participants were recruited through a website and those who reported that they were in good health voluntarily took part in the experiment (None of the 39 participants reported a health problem). First, participants were required to confirm a consent form, which described the purpose of the study as to “reveal driving behavior,” ensuring participants’ right to quit the experiment anytime without a reason. Participants filled in the consent form as well as a bank transfer form.

Driving session. Informed consent was followed by a 10-minute practice session, where participants were instructed to drive straightforward in the left lane on an urban highway at the speed they felt was safe by checking a speedometer and the image of side mirrors as needed. All participants finished a practice session in 10 minutes. Participants were asked if they were in good health after the practice session, then only those who reported no health problem (all of the participants) performed the driving session, where the speedometer was covered with a sheet of black paper and the image of side mirrors were not available. In the driving session, participants were instructed to drive a coupe straightforward in the left lane on a highway at the speed they felt was safe until the road disappeared. It averaged about 30 minutes, slightly differing from person to person. The room was darkened during the practice and driving sessions, and participants' cell phones were set to silent mode during the driving session so that participants could concentrate on driving. Logs were automatically recorded by UC-win/Road. Figure 8 shows a participant in the driving session.

Figure 8. A participant in the driving session.

Questionnaire session. Participants responded to the CG Animation Questionnaire on a laptop computer after the driving session. The order of the videos was counterbalanced between participants. The CG Animation Questionnaire was followed by the Grid Image Questionnaire, where participants were instructed to circle the areas they specifically looked at or took care of during the driving session in each image of a road marking. The order of the images was counterbalanced between participants. After they completed the questionnaire, participants were asked if they noticed the convergence of some road marking intervals.

Data analyses. Participants' demography was aggregated with Microsoft Office Excel 2013 and statistical analyses on the data recorded by UC-win/Road were performed using PASW Statistics 18.0. As recommended in Girden (1992), when Mauchly's sphericity test indicated that the assumption of sphericity had been violated, the Greenhouse-Geisser correction was applied when epsilon was .75 or below and the Huynh-Feldt correction was applied if epsilon was larger than .75.

Mean speed and throttle. Speeds were recorded at 200 m prior to the beginning of a first clothoid curve through 100m prior to the beginning of a first clothoid curve (S_1), at 100 m prior to the beginning of a first clothoid curve through the beginning of a first clothoid curve (KA_1) (S_2), and at the beginning of a first clothoid curve (KA_1) through the end of a simple curve (KA_2) (S_3). For speed-related measures, paired *t*-tests were conducted in S_1, S_2, and S_3 to examine the effects of the existence of road markings, followed by a repeated measures ANOVA if a paired *t*-test revealed any significant difference in the section. Readers must note an increase in type I errors could not be avoided in this process.

Standard deviation of lane position. For standard deviation of lane position, a one-way repeated measures ANOVA was performed in simple curves, where curvature hits the greatest value.

CG Animation Questionnaire. A one-way repeated measures ANOVA was performed on each item, followed by a post hoc comparisons with a Bonferroni correction when an ANOVA revealed any significance.

Grid Image Questionnaire. Heat maps of each condition were generated based on the number of squares overlapping more than a half of the areas participants circled.

Protocol. Participants' time was compensated by 1,000 Japanese yen. The experimental protocol had been approved by the Ethical Committee of Behavioral Sciences, Faculty of Human Sciences Osaka University.

Results

A participant's log file had been permanently lost due to a program crash. In addition, 10 out of 39 participants were missing data indicating their lane position because of defective settings in the driving simulator. Thus sample size varies across the measures: 38 for speed-related measures, 28 for lane position, and 39 for the CG Animation Questionnaire as well as for the Grid Image Questionnaire.

Mean Speed

Table 3 exhibits mean speeds in the *Control* and *Treatments* conditions in S_1 through S_3. In the *Treatments* condition, mean speed dropped 0.77 km/h (0.85%) in S_1, 1.42 km/h (1.55%) in S_2, and 0.67 km/h (0.81%) in S_3 compared to the speed in the *Control* condition. A paired *t*-test with a Bonferroni correction revealed a significant difference on mean speed in S_2, $t(37) = 2.37$, $p = .046$, while no significant differences were found in S_1 ($t(37) = 1.23$, $p = .452$, *n.s.*) and S_3 ($t(37) = 0.98$, $p = .666$, *n.s.*). Table 4 shows mean speeds in each condition in S_2.

For S_2, Mauchly's sphericity test indicated that the assumption of sphericity had been violated in marking shape ($\chi^2(5) = 12.54$, $p = .028$) as well as in interaction of shape and interval ($\chi^2(5) = 29.31$, $p = .000$). As a result, the degrees of freedom modified with the Huynh-Feldt correction and the Greenhouse-Geisser correction were respectively applied to shape ($\varepsilon = .87$) and interaction of shape and interval ($\varepsilon = .67$). Although a two-way repeated measures ANOVA (Table 5) did not reveal a main effect for shape ($F(2.62, 96.95) = 0.58$, $p = .605$, $\eta_p^2 = 0.02$, *n.s.*) or for interaction of shape and interval ($F(1.91, 70.73) = 0.31$, $p = .728$, $\eta_p^2 = 0.01$, *n.s.*), it found a marginal main effect for interval, $F(1, 37) = 3.87$, $p = .057$, $\eta_p^2 = 0.10$), indicating lower driving speed in *Constant* condition ($M = 89.79$ km/h, $SD =$

21.25 km/h) than in *Convergent* condition (*M* = 90.49 km/h, *SD* = 21.21 km/h). Figure 9 shows mean speeds in *None*, *Constant*, and *Convergent* conditions at a curve.

Table 3

Mean Speeds in the Control and Treatments Conditions in S_1 through S_3

		95% CI	
Section[a]	*M* (*SD*)	*LL*	*UL*
Control			
S_1	90.67 (21.09)	83.74	97.61
S_2	91.88 (21.16)	84.93	98.83
S_3	83.63 (18.90)	77.42	89.85
Treatment			
S_1	89.90 (20.79)	83.07	96.73
S_2	90.46 (21.35)	83.44	97.48
S_3	82.96 (19.64)	76.50	89.41

Note. CI = confidence interval; *LL* = lower limit, *UL* = upper limit.

[a]*n* = 38

Table 4

Mean Speeds in Each Condition in S_2

Condition[a]	*M* (*SD*)	95% CI	
		LL	*UL*
Parallelogram Edge Line			
Constant	90.40 (20.89)	83.53	97.26
Convergent	90.52 (22.10)	83.26	97.79
Wide Chevron			
Constant	90.06 (21.61)	82.96	97.17
Convergent	90.51 (21.73)	83.37	97.65
Narrow Chevron			
Constant	89.20 (21.68)	82.08	96.33
Convergent	90.28 (20.63)	83.50	97.06
Optical Dots			
Constant	89.51 (21.95)	82.30	96.73
Convergent	90.66 (21.15)	83.71	97.62
Overall			
Constant	89.79 (21.25)	82.81	96.78
Convergent	90.49 (21.21)	83.52	97.47

Note. CI = confidence interval; *LL* = lower limit, *UL* = upper limit.

[a]$n = 38$

Table 5

One-Way ANOVA of Main Speed in S_2

Source	*SS*	*df*	*MS*	*F*	*p*
Shape	21.52	2.62	8.21	0.58	.605
Interval	37.35	1	37.35	3.87	.057
Shape × interval	14.08	1.91	7.36	0.31	.728

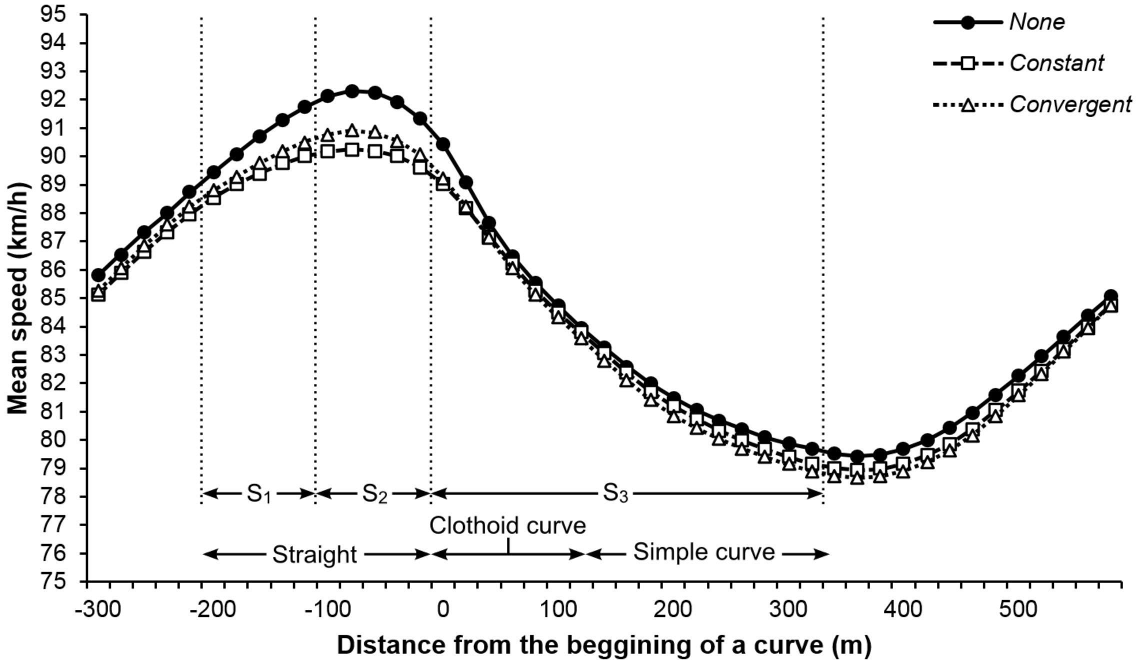


Figure 9. Mean speeds in *None*, *Constant*, and *Convergent* conditions at a curve.

Throttle

Table 6 exhibits mean throttle values in the *Control* and *Treatments* conditions in S_1 through S_3. In the *Treatments* condition, mean throttle dropped 3.82 percentage points in S_1, 1.48 percentage points in S_2, and 0.67 percentage points in S_3 compared to the speed in the *Control* condition. A paired *t*-test with the Bonferroni correction revealed a significant difference on mean throttle in S_1, $t(37) = 3.00$, $p = .015$, while no significant difference was found in S_2 ($t(37) = 1.19$, $p = .723$, *n.s.*) and S_3 ($t(37) = 0.98$, $p = .459$, *n.s.*). Table 7 shows mean throttle values in each condition in S_1.

For S_1, Mauchly's sphericity test indicated that the assumption of sphericity had been violated in marking shape ($\chi^2(5) = 24.83$, $p = .000$), therefore the degrees of freedom modified with the Huynh-Feldt correction was applied ($\varepsilon = .78$). Although a two-way repeated measures ANOVA (Table 8) did not find significant main effects for marking shape ($F(2.34, 86.54) = 1.27$, $p = .289$, $\eta_p^2 = 0.03$, *n.s.*) or for interaction of shape and interval ($F(3, 111) = 1.07$, $p = .367$, $\eta_p^2 = 0.03$, *n.s.*), it revealed a marginal main effect for marking interval on throttle, $F(1, 37) = 3.15$, $p = .084$, $\eta_p^2 = 0.08$, indicating lower throttle value in the *Constant* condition (39.59%) than in the *Convergent* condition (42.13%). Figure 10 shows mean throttle values in *None*, *Constant*, and *Convergent* conditions at a curve.

Table 6

Mean Throttle Values in the Control and Treatments Conditions in S_1 through S_3

		95% CI	
Section[a]	*M* (*SD*)	*LL*	*UL*
Control			
S_1	44.58 (17.58)	38.80	50.36
S_2	30.37 (13.51)	25.93	34.81
S_3	21.55 (10.79)	18.00	25.10
Treatment			
S_1	40.76 (18.67)	34.62	46.90
S_2	28.89 (14.71)	24.06	33.72
S_3	20.88 (10.18)	17.53	24.23

Note. All units are in %. CI = confidence interval; *LL* = lower limit, *UL* = upper limit.

[a]*n* = 38

Table 7

Mean Throttle Values in Each Condition in S_1

		95% CI	
Condition[a]	*M* (*SD*)	*LL*	*UL*
Parallelogram Edge Line			
Constant	39.59 (18.08)	33.65	45.53
Convergent	42.13 (20.26)	35.48	48.79
Wide Chevron			
Constant	41.33 (18.78)	35.16	47.51
Convergent	41.51 (18.29)	35.50	47.52
Narrow Chevron			
Constant	38.67 (19.45)	32.27	45.06
Convergent	41.47 (17.56)	35.70	47.24
Optical Dots			
Constant	39.01 (20.25)	32.35	45.66
Convergent	39.14 (18.39)	33.10	45.19
Overall			
Constant	39.65 (18.04)	33.72	45.58
Convergent	41.06 (17.72)	35.24	46.89

Note. All units are in %. CI = confidence interval; *LL* = lower limit, *UL* = upper limit.

[a]*n* = 38

Table 8

One-Way ANOVA of Mean Throttle Value in S_1

Source	*SS*	*df*	*MS*	*F*	*p*
Shape	0.02	2.34	0.01	1.27	.289
Interval	0.02	1	0.02	3.15	.084
Shape × interval	0.01	3	0.00	1.07	.367

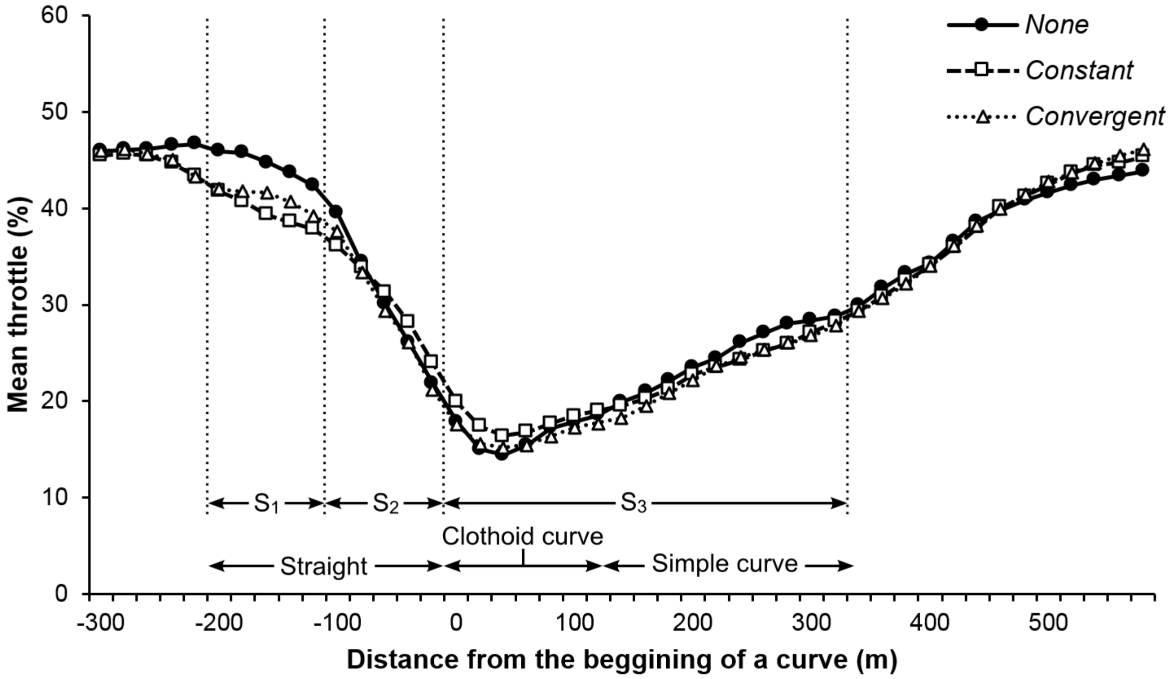


Figure 10. Mean throttle values in *None*, *Constant*, and *Convergent* conditions at a curve.

Standard Deviation of Lane Position

Table 9 exhibits standard deviation of lane position in each condition in a simple curve while Figure 11 displays changes in standard deviation of lane position with each marking. Standard deviations of lane position was stable before it increased at a simple curve, where a mean value of standard deviation of lane position was 7.26 (*SD* = 3.08) cm in *None*, 7.13 (*SD* = 1.84) cm in *Parallelogram Edge Line*, 7.14 (*SD* = 2.31) cm in *Wide Chevron*, 7.32 (*SD* = 2.32) cm in *Narrow Chevron*, and 7.24 (*SD* = 2.45) cm in *Optical Dots* conditions. Mauchly's sphericity test indicated that the assumption of sphericity had been violated ($\chi^2(9) = 22.17$, $p = .008$), therefore the degree of freedom modified with the Greenhouse-Geisser correction was applied ($\varepsilon = .72$). A one-way ANOVA (Table 10) did not reveal a significant effect for marking shape, $F(2.87, 77.55) = 0.09$, $p = .961$, $\eta_p^2 = 0.00$, *n.s.*). Each participants' standard deviation of lane position in each condition was plotted in a control chart (Figure 12). As seen in Figure 12, Participants 15 and Participants 26 showed relatively unstable lateral positions in *None* while they did not swerve in other conditions with the road markings.

Table 9

Standard Deviation of Lane Position in Each Condition in a Simple Curve

Condition[a]	*M* (*SD*)	95% CI *LL*	95% CI *UL*
None	7.26 (3.08)	6.25	8.28
Parallelogram Edge Line	7.13 (1.84)	6.53	7.73
Wide Chevron	7.14 (2.31)	6.38	7.90
Narrow Chevron	7.32 (2.32)	7.32	7.32
Optical Dots	7.24 (2.45)	6.44	8.04

Note. All units are in cm. CI = confidence interval; *LL* = lower limit, *UL* = upper limit.

[a]*n* = 28

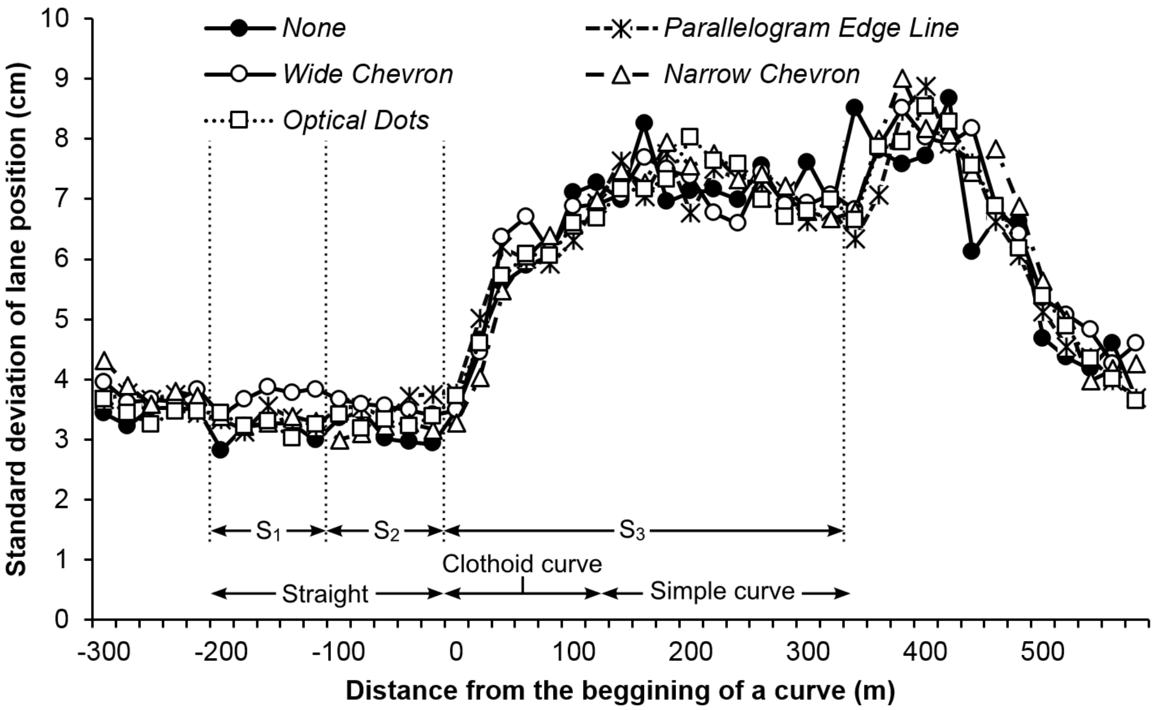


Figure 11. Standard deviation of lane position at a curve.

Table 10

One-Way ANOVA of Standard Deviation of Lane Position in a Simple Curve

Source	*SS*	*df*	*MS*	*F*	*p*
Shape	0.78	2.87	0.27	0.09	.961

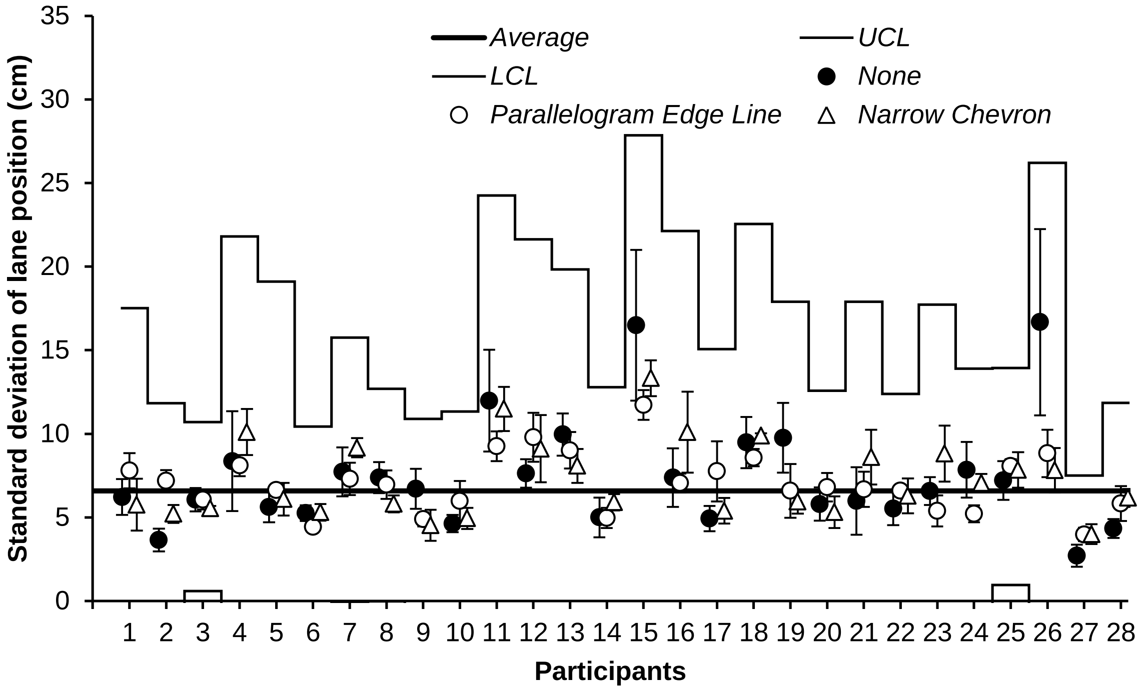


Figure 12. Control charts of standard deviation of lane position at a simple curve. Error bars represent standard errors. Points are offset horizontally so that error bars can be seen. *UCL* = upper control limit (*M* + 3 *SD*), *LCL* = lower control limit (*M* − 3 *SD*).

CG Animation Questionnaire

Figure 13 exhibits ratings in each condition in the CG Animation Questionnaire and Table 11 exhibits one-way ANOVAs of the CG Animation Questionnaire.

***Feel of Danger*.** A one-way repeated measures ANOVA found a significant effect of marking patterns on subjective ratings, $F(4, 152) = 7.20$, $p = .001$, $\eta_p^2 = 0.16$. Post hoc comparisons with a Bonferroni correction showed that *Feel of Danger* was rated significantly higher in *Wide Chevron* ($p = .000$) and *Optical Dots* ($p = .001$) than in *None* and in *Wide*

Chevron than in *Narrow Chevron* (p = .017).

Feeling of Speeding. A one-way repeated measures ANOVA found a significant effect of marking patterns on subjective ratings, F(4, 152) = 19.04, p = .000, η_p^2 = 0.33. Post hoc comparisons with a Bonferroni correction showed that *Feeling of Speeding* was rated significantly higher in *Parallelogram Edge Line* (p = .001), *Wide Chevron* (p = .000), *Narrow Chevron* (p = .000), and *Optical Dots* (p = .000) than in *None*.

Eyes on the Road. A one-way repeated measures ANOVA found a significant effect of marking patterns on subjective ratings, F(4, 152) = 67.07, p = .000, η_p^2 = 0.64. Post hoc comparisons with a Bonferroni correction showed that *Eyes on the Road* was rated significantly higher in *Parallelogram Edge Line* (p = .004), *Wide Chevron* (p = .000), *Narrow Chevron* (p = .000), and *Optical Dots* (p = .000) than in *None*, in *Wide Chevron* (p = .000), *Narrow Chevron* (p = .000), and *Optical Dots* (p = .000) than in *Parallelogram Edge Line*, in *Wide Chevron* (p = .016) than in *Narrow Chevron*, and in *Optical Dots* (p = .000) than in *Narrow Chevron*.

Driving Difficulty. Mauchly's sphericity test indicated that the assumption of sphericity had been violated (χ^2(9) = 19.31, p = .023), therefore the degrees of freedom modified with the Huynh-Feldt correction was applied (ε = .88). A one-way repeated measures ANOVA found a significant effect of marking patterns on subjective ratings, F(3.51, 133.31) = 12.71, p = .000, η_p^2 = 0.25. Post hoc comparisons with a Bonferroni correction showed that *Driving Difficulty* was rated significantly higher in *Wide Chevron* (p = .000) and *Optical Dots* (p = .006) than in *None*, in *Wide Chevron* (p = .000) and in *Optical Dots* (p = .001) than in *Parallelogram Edge Line*, in *Wide Chevron* (p = .000) than in *Narrow Chevron*, and in *Optical Dots* (p = .005) than in *Narrow Chevron*.

Difficulty of Grasping Distance. Mauchly's sphericity test indicated that the assumption of sphericity had been violated ($\chi^2(9) = 25.66$, $p = .002$), therefore the degrees of freedom modified with the Huynh-Feldt correction was applied ($\varepsilon = .79$) A one-way repeated measures ANOVA found a significant effect of marking patterns on subjective ratings, $F(3.16, 119.98) = 5.11$, $p = .003$, $\eta_p^2 = 0.12$. Post hoc comparisons with a Bonferroni correction showed that *Difficulty of Grasping Distance* was rated significantly higher in *Wide Chevron* ($p = .006$) and *Optical Dots* ($p = .038$) than in *Parallelogram Edge Line*, in *Wide Chevron* ($p = .000$) than in *Narrow Chevron*, and in *Optical Dots* ($p = .040$) than in *Narrow Chevron*.

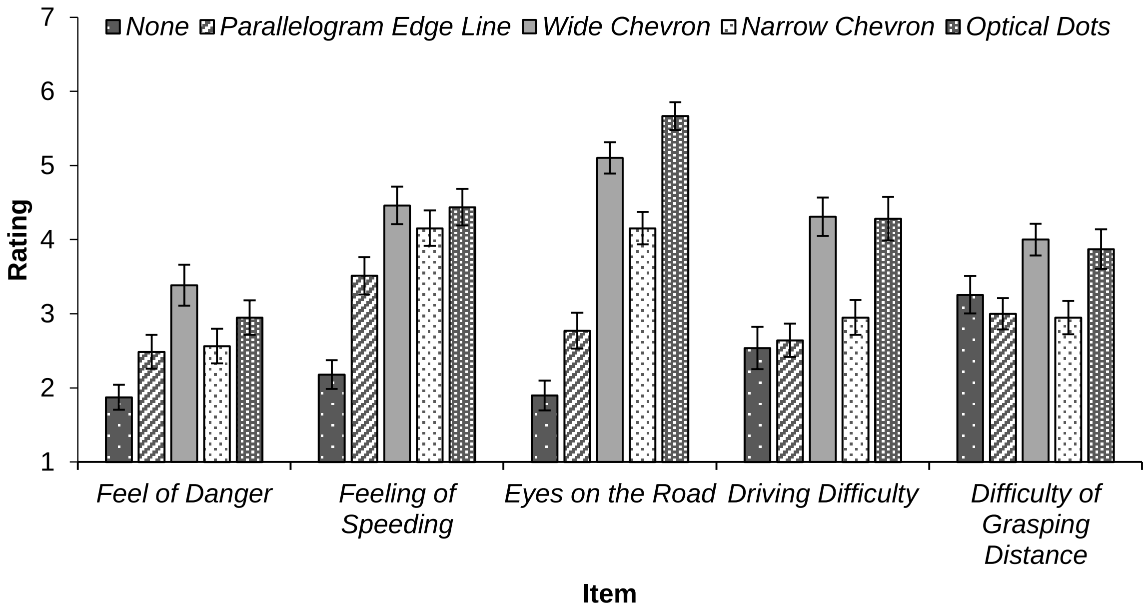


Figure 13. One-way ANOVAs of the CG Animation Questionnaire. Error bars represent standard errors. Each scale was evaluated on the seven-point Likert scale ("1 – Strongly disagree," "2 – Disagree," "3 – Disagree somewhat," "4 – Neither agree nor disagree," "5 – Agree somewhat," "6 - Agree," "7 – Strongly agree").

Table 11

One-Way ANOVAs of the CG Animation Questionnaire

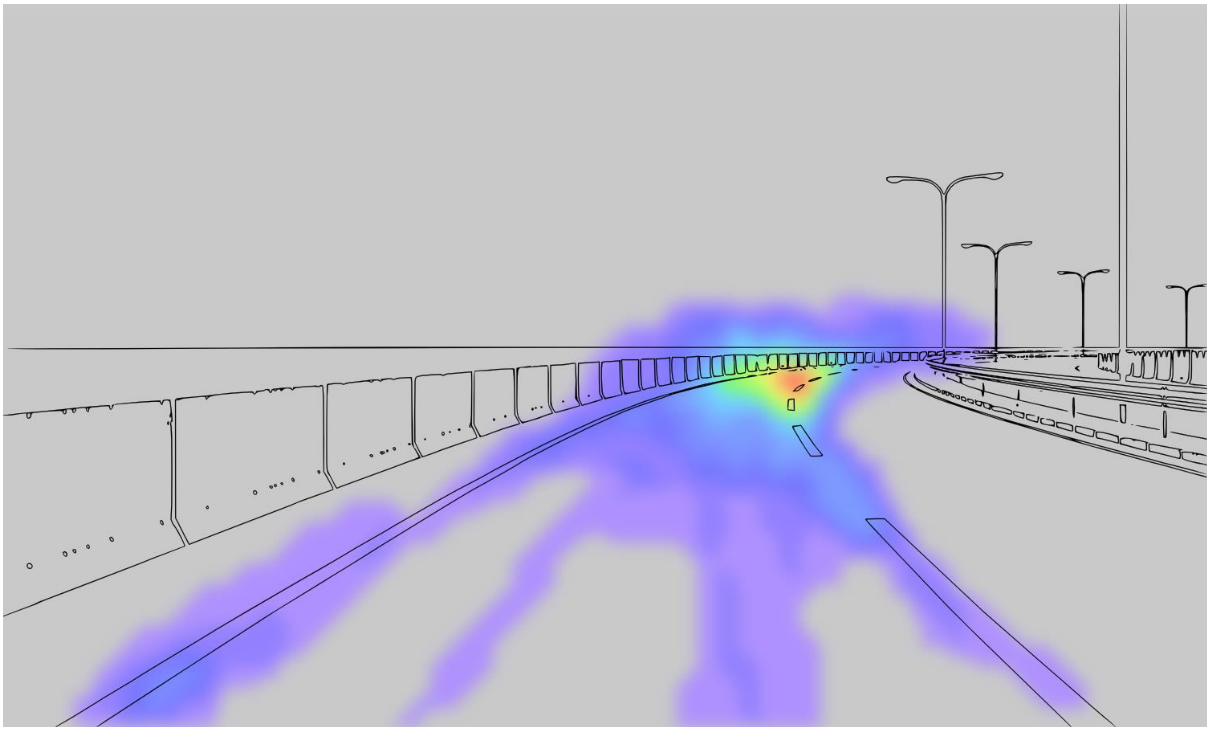
Source	*SS*	*df*	*MS*	*F*	*p*
Feel of Danger	49.47	4	12.37	7.20	.000
Feeling of Speeding	142.84	4	35.71	19.04	.000
Eyes on the Road	386.84	4	96.71	67.07	.000
Driving Difficulty	121.21	3.51	34.55	12.71	.000
Difficulty of Grasping Distance	37.66	3.16	11.93	5.11	.002

Grid Image Questionnaire

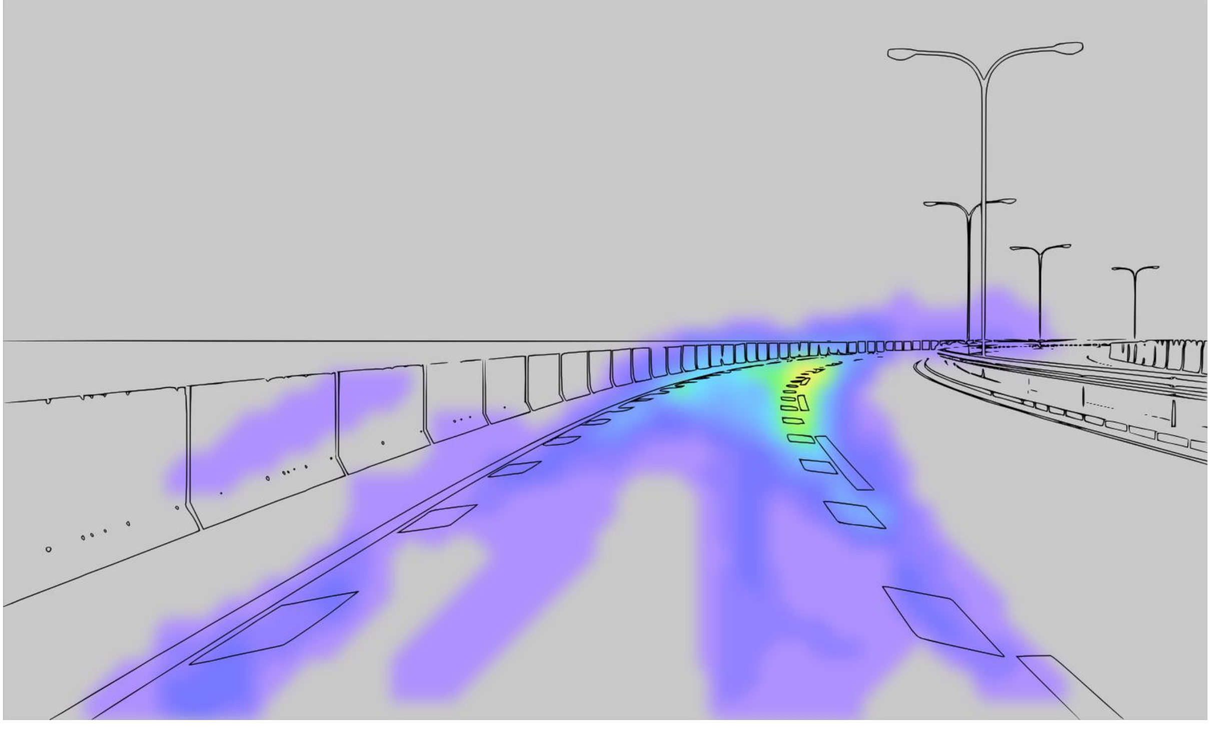
Figure 14 shows images generated from the Grid Image Questionnaire. Participants' attention had been concentrated on the apex of the inner division line in *None* condition. Although they also paid attention to the same area in *Parallelogram Edge Line* condition, the depth of concentration was smaller in *Parallelogram Edge Line* than in *None*, indicating relatively higher attention to the near side of the inner division line as well as to the far side of the outer division line. *Wide Chevron* and *Narrow Chevron* both showed a line of attentional concentration along the center of the patterns though the depth of concentration was larger in *Narrow Chevron*. A larger amount of attention was laterally scattered in *Wide Chevron* than in *Narrow Chevron*. In *Optical Dots* condition, participants paid attention to the relatively wider area across the markings.

The number of people who reported that they noticed the interval convergence was 3 (7.69%) in *Parallelogram Edge Line* and *Narrow Chevron* conditions whereas 7 (17.95%) participants noticed the convergence in *Wide Chevron* and *Optical Dots* conditions, respectively (Table 12). A Cochran's Q test revealed the number of participants who were aware of the convergence was lower in *Parallelogram Edge Line* and *Narrow Chevron* than in *Wide Chevron* and *Optical Dots* (p = 0.470).

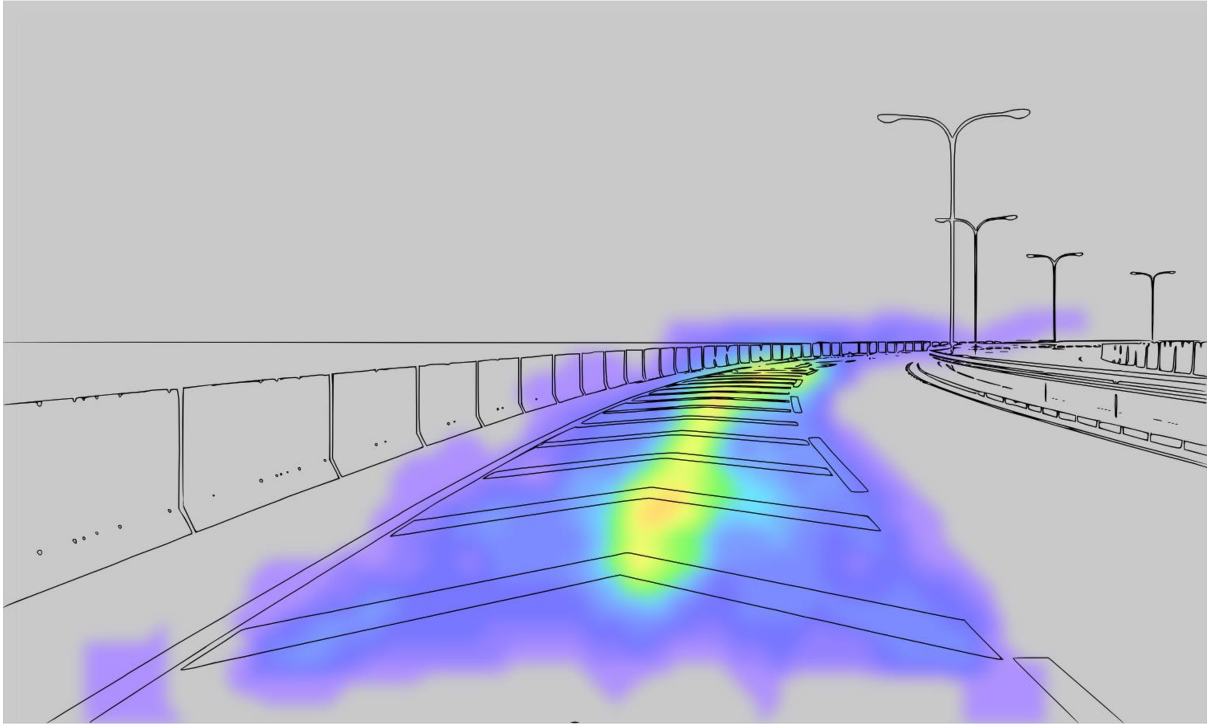
None



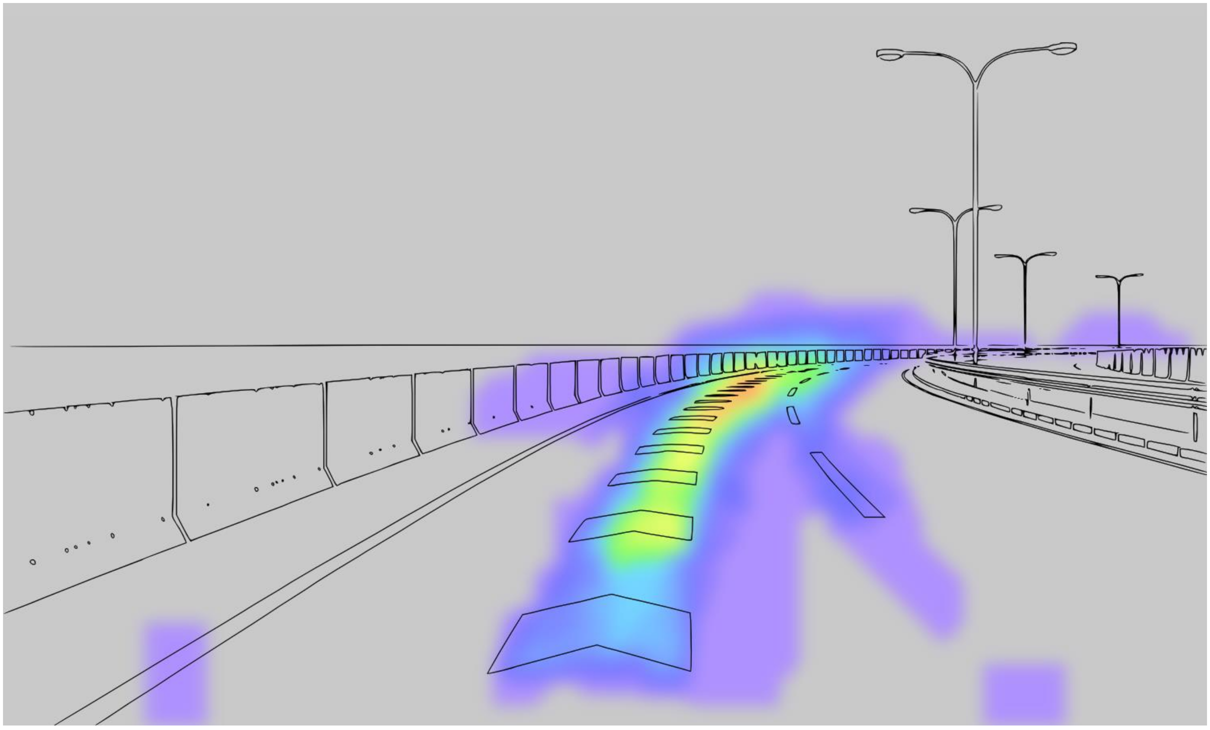
Parallelogram Edge Line



Wide Chevron



Narrow Chevron



Optical Dots

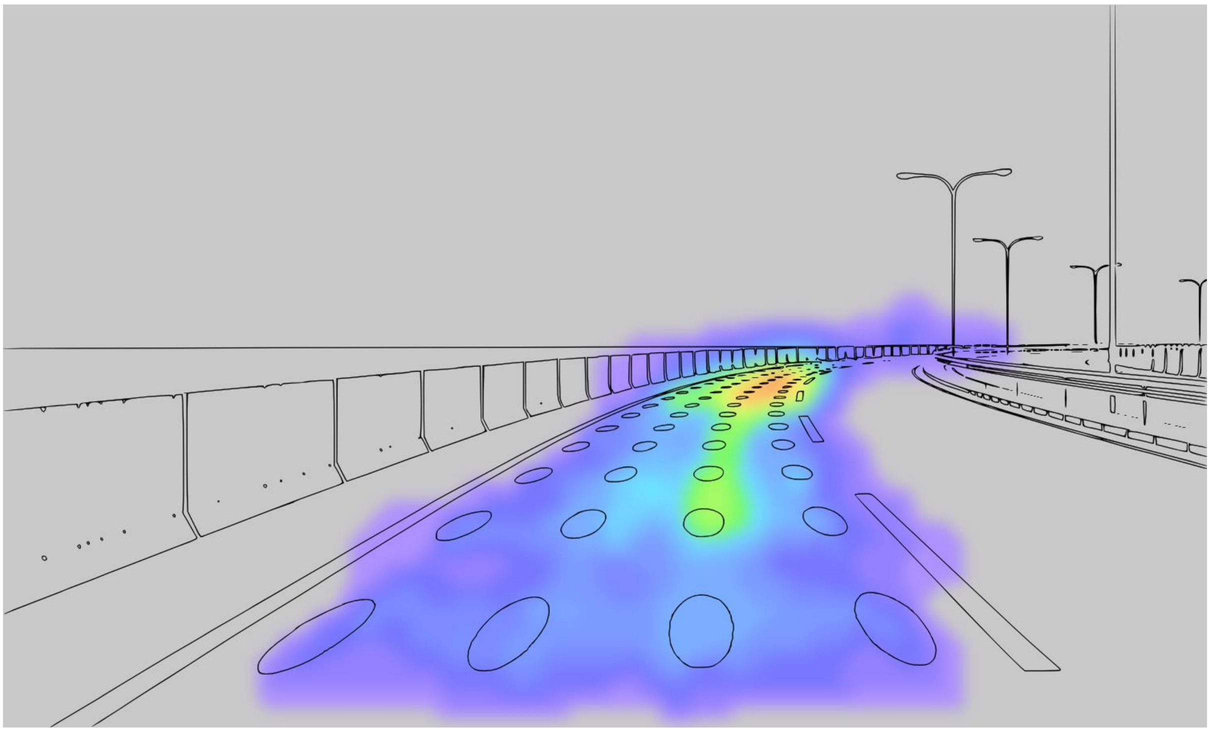


Figure 14. Heat maps indicating the areas attracting participants' attention in each marking pattern. Red indicates a high level of attention while blue shows lower level of attention.

Table 12

Numbers of People Who Noticed the Interval Convergence in Each Condition

Condition[a]	Noticed	Unnoticed
Parallelogram Edge Line	3	36
Wide Chevron	7	32
Narrow Chevron	3	36
Optical Dots	7	32

Note. [a]n = 39

Discussion

The purpose of this study was to explore the effects of road marking patterns on driving speed and lane position in association with drivers' subjective feelings and mental workload as well as visual attention.

Driving Speed

The presence of the road markings lowered mean speed by 1.42 km/h (1.55%) only at the 100-0 m preceding a clothoid curve. In this section, participants tended to drive at 0.7 km/h (0.77%) slower with the road markings with the constant interval than with the road markings with the converging interval. Since the longitudinal marking density was higher in the road markings with constant interval than with the road markings with the converging interval, this result indicates that the road markings for speed reduction as short as 200 m work as warning devices rather than as perceptual cues that increase the subjective speed.

In addition to vehicle speed, throttle values were also investigated as an indicator of mental process. The presence of road markings lowered mean throttle by 3.82 percentage points only at the beginning of the road markings during the 100 m preceding a curve. In this section, participants tended to push 2.54 percentage points less pedal with the road markings with constant interval than with the road markings with the converging interval. Because reaction time while at the wheel is said to be 0.5 seconds (Drakopoulos & Vergou, 2003), drivers' mental process of speed adjustment by the road markings was assumed to have started about 13 m preceding the markings. As pointed out by Godley et al. (1999), this also implies the alarming effect.

The most important finding of this study is that both throttle and mean speed tended to drop more with the road markings with constant interval than with the road markings with the converging interval. Many studies investigating the feeling of acceleration (e.g., Denton, 1980) have compared road markings with converging intervals to those with a fixed interval that was equal to the maximum interval of a set of converging intervals. However, it is not possible in this design to claim the effect of illusion even if driving speeds were lower in the converging condition than in the constant condition because the longitudinal marking density, which could be alarming, in the converging intervals is higher than that in the constant interval. In other words, any speed reductions in a study with such an experimental design could not be due to the illusion of acceleration, but might be because of an alarming effect. To rule out this possibility, the present study used the minimum interval in a set of converging intervals as a fixed interval in the other condition.

In this study, an alarming effect was observed as seen in Godley et al. (1999), Jamson et al. (1999), and Jarvis and Jordan (1990), while the effect of acceleration illusion was not observed in the present study since both driving speed and throttle are not larger in the road markings with a converging interval than with the road markings with a fixed interval through all sections.

Although the effect of the acceleration illusion was not observed in this study, the results do not necessarily deny the presence of the acceleration illusion in other situations because the illusion of speeding and the alarming effect are not mutually exclusive.

Most of the participants did not realize the convergence of marking intervals. This result suggested the possibility of using road markings as unobtrusive perceptual countermeasures if road markings can elicit the feeling of acceleration. The reason why more participants were aware of the convergence of marking interval in *Wide Chevron* and *Optical Dots* than in *Parallelogram Edge Line* and *Narrow Chevron* is unclear. One possibility could be that the participants were able to grasp their driving speeds more accurately with the wider road markings by peripheral vision as suggested by the idea of optic flow since the length of a vector per period is bigger in the peripheral visual field than in the foveal visual field (Gibson, 1979).

Due to the lack of sample size, the researcher did not perform a post hoc analysis between participants who were aware of the convergence and those who were not. Future research, however, could reveal the nature of road markings by comparing objective variables in association with subjective variables.

Lane Position Variance

No significant effects of the road markings on standard deviation of lane position were revealed since there was a floor effect on standard deviation of lane position. It was difficult to make a discussion based on statistical data in the present study because of the small values of standard deviation of lane position compared to other simulation studies (e.g., Dijksterhuis et al., 2011; He et al., 2014).

Thus each participants' standard deviation of lane position in each condition were plotted in a control chart (Figure 13), a chart used to monitor unusual values. Although statistical tests are not available in a control chart, it is commonly used in the field of traffic safety (e.g., pavement quality monitoring) because of the importance of monitoring unusual values (Spiegelman, Park, & Rilett, 2010). The control chart showed that Participant 15 and Participant 26 had relatively unstable lateral positions in the *None* condition while they did not swerve in other conditions with the road markings.

In the CG Animation Questionnaire, *Driving Difficulty* was rated relatively high in *Wide Chevron* and *Optical Dots* than in the other road markings. As for lane position, *Driving*

Difficulty is thought to be important as long as high workload is a potential contributor to smaller lane position variance as He et al. (2014) points out. Yet further research on the effects of road markings on workload should be carried out since lane position variance was not assessed enough in the present study.

The Grid Image Questionnaire brought some insights on drivers' visual attention. In line with Land and Lee (1994), participants tended to look at the apex of inner division line when no road markings were present. With *Parallelogram Edge Line*, participants paid more attention to the near side of the inner division line as well as to the far side of the outer division line, suggesting participants could have been aware of virtual lane narrowing though smaller *Eyes on the Road* in comparison to those in the other road markings that suggested that participants did not fixate on the markings. In contrast, participants paid attention to the lane center with *Wide Chevron* and *Narrow Chevron*. This is in line with the aim of these types of road marking as steering guidance. The potential function of *Optical Dots* as a steering guidance was also implied because participants' attention was larger along with the second longitudinal series of dots from the inner division line. Furthermore, these road markings may help drivers accurately scan curvature.

Combining the results of the control chart and the Grid Image Questionnaire, the road markings' potential ability of lane position keeping was implied, though further research is required. The present study could not fully investigate the role of visual attention on lane keeping behavior due to the floor effect. Since participants hardly swerved on the course, future simulation studies may need to make curve radii smaller experimentally. Also, the Grid Image Questionnaire was not a perfect tool to explore visual attentional patterns because it cannot reveal automated attentional distributions or unconscious eye movements. Analyses using a dynamic eye camera will allow more detailed discussions in future research.

Suggestions

The result of the present study is especially meaningful in that alarming effect dominated through the road markings as short as 200 m since it is the marking distance preceding a hazardous curve in highways in Japan. The effect of road markings, however, should be investigated on roads too. Although there was no significant effect of marking shape in the present study, this result does not deny the possible difference of the effects in different situations on real roads.

Since the alarming effect dominated in the present study, road markings with larger *Feel of Danger* and *Driving Difficulty*, such as *Wide Chevron* and *Optical Dots*, may have a potential to be relatively powerful countermeasures for initial speed reduction compared to those rated high in *Feeling of Speeding* though *Wide Chevron* and *Optical Dots* somewhat might not be as safe as the others due to high ratings in *Difficulty of Grasping Distance*. Although Adachi et al. (2009) aimed to achieve smaller *Driving Difficulty* in the process of selecting an optimal “sequence design” on a tunnel wall, that may not be the case on road markings.

To sum up the findings, it is recommended to introduce road markings with a high alarming potential (e.g., *Wide Chevron* and *Optical Dots*) on the preceding a hazardous curve for speed reduction whereas it would be effective to install road markings as steering guides (e.g., *Parallelogram Edge Line* and *Narrow Chevron*) in a curve.

Regulations and Research Recommendations

There were some regulations in the present study.

First, the participants were quite young (*M* = 22.55 years old, *SD* = 5.08 years old) and inexperienced (*M* = 2.89 years, *SD* = 4.95 years) compared to the general population of drivers though they had been driving on a daily basis. As Mourant and Rockwell (1970) pointed out that different eye searching patterns are different between novice drivers and experienced drivers, a different population from that of the present study should be recruited in future research.

Second, the steering torque of the driving simulator did not change no matter how large the participants steered. Although the reason why it did not change was unknown, it lacked validity so that the participants' steering behavior might have been affected in an unsuitable way. Future research investigating lane position needs a driving simulator with higher fidelity.

It is worth investigating the effects of road markings in other situations. Although a clear alarming effect was shown in the present study, the illusion of acceleration may be observed in longer treatment sections as Godley et al. (1999) and Han et al. (2012) claim. In addition, the magnitudes of the effects of road markings in urban conditions can differ from those in rural conditions, though most of the simulation experiments have been carried out on rural roads (Weller, 2010). Thus it would be meaningful to investigate the effects of road markings in urban situations.

Marking conspicuity also can be an object of research as an attempt to achieve stronger or lasting effects of road markings. Different colors of road markings might give drivers different perceptions while a gradual increase in road marking visibility towards the travelling direction in long sections may achieve unobtrusiveness so that drivers would be less likely to adapt to the road markings.

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Appendix A

Parameters of driving simulation

Critical parameters of driving simulation are shown in Table A.

Table A1

Critical Parameters of Driving Simulation

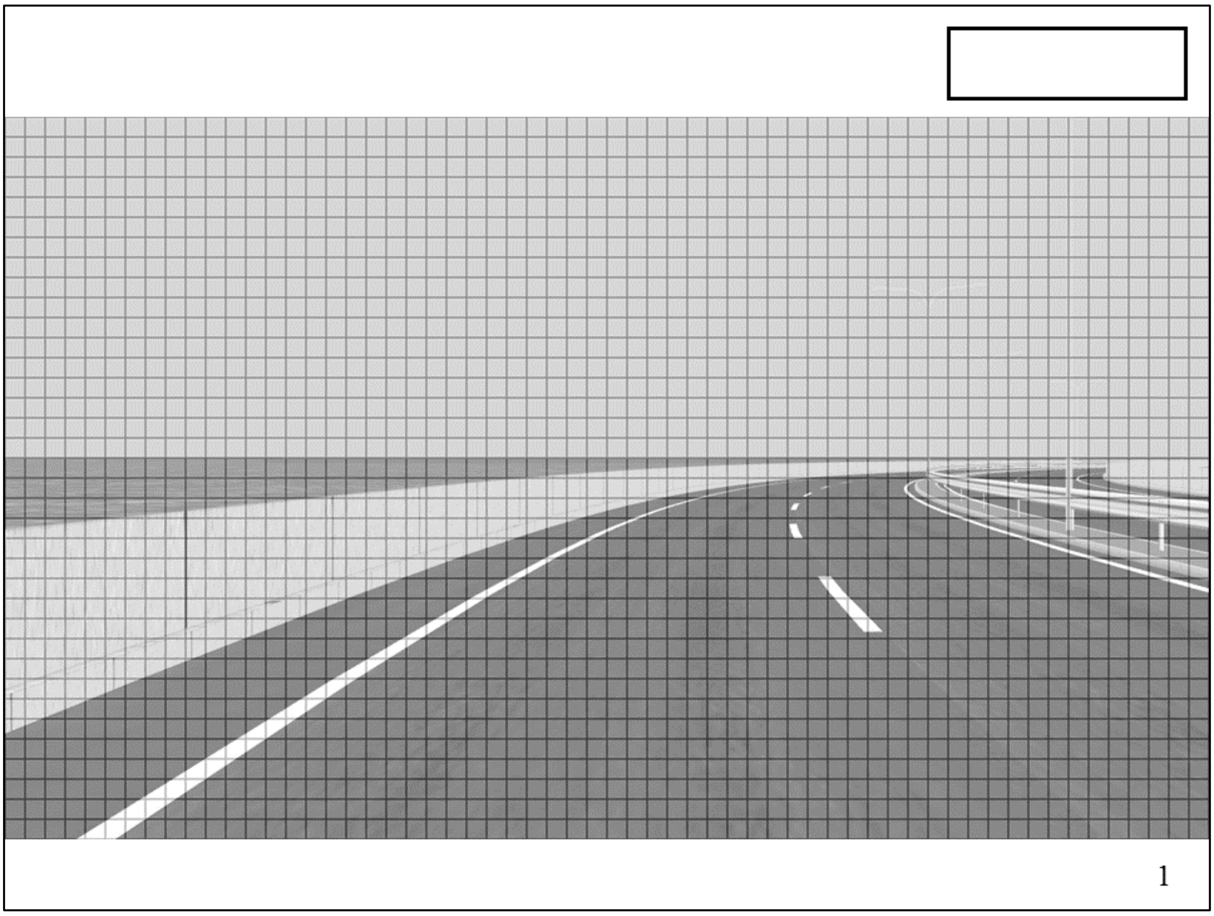
Parameter	Value
Rotational resistance coefficient value	0.010
Rotational resistance speed coefficient value	7.00×10^{-6}
Vehicle type	Coupe
Traffic flow	60 km/h at 7.2-second intervals

Appendix B

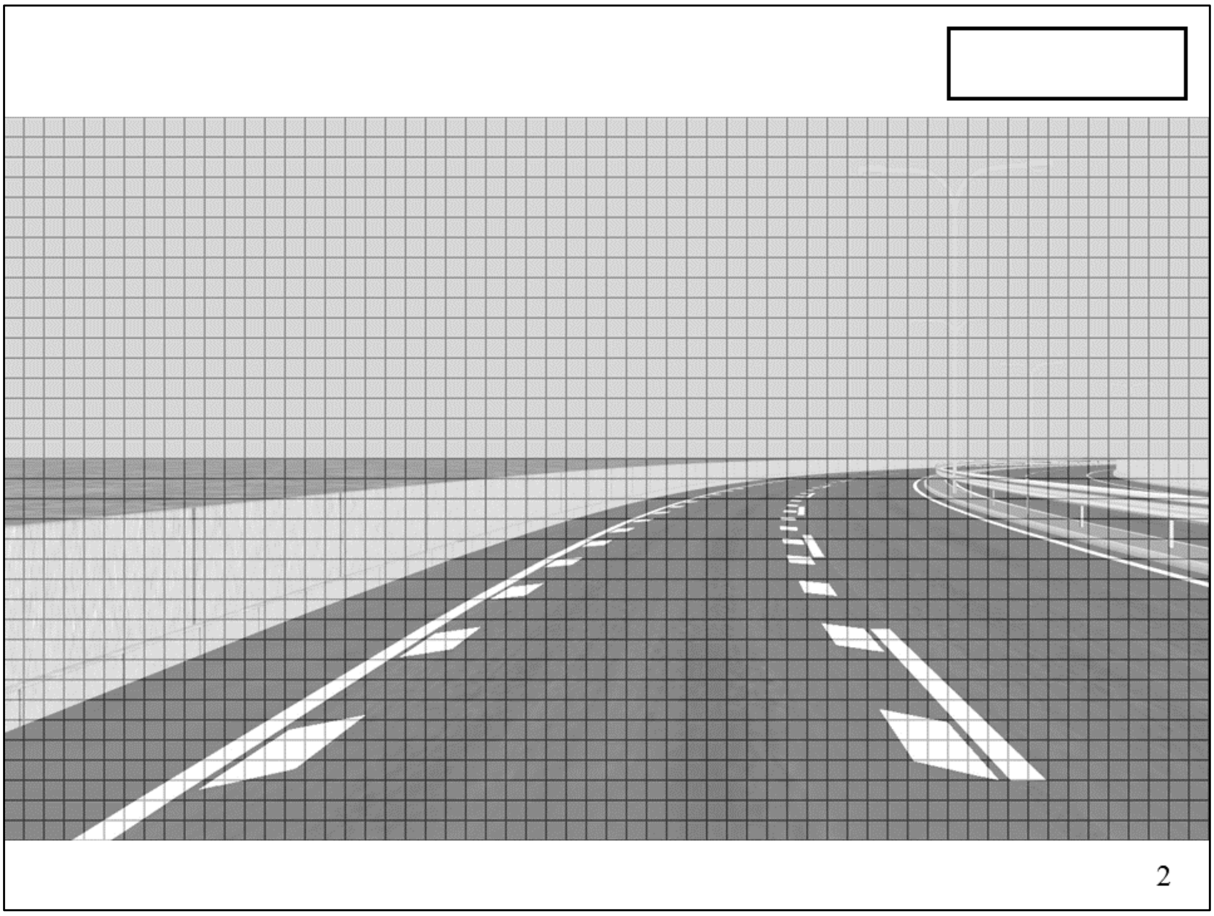
Grid Image Questionnaire

All sheets in the Grid Image Questionnaire are shown in Figure B1. Raw data from the Grid Image Questionnaire are shown in Figure B2.

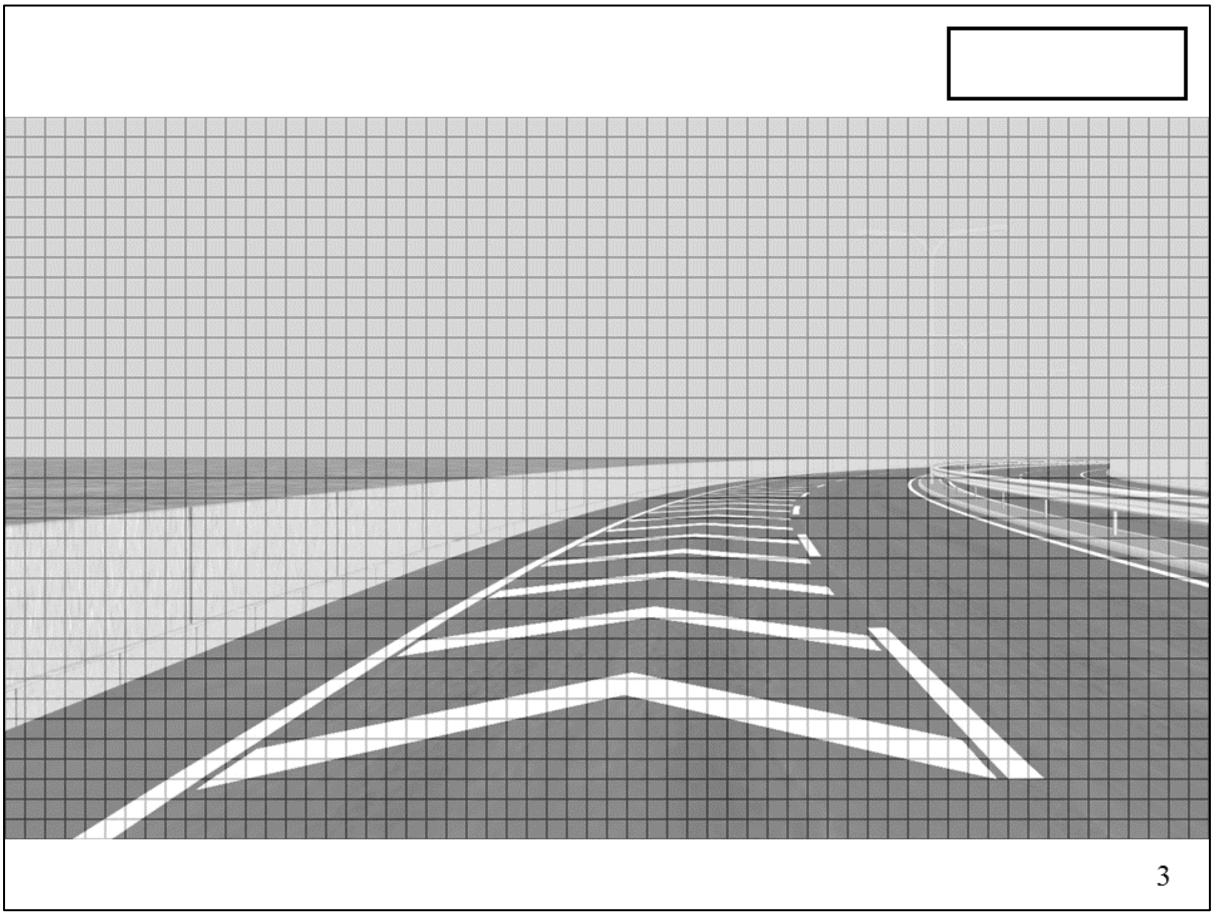
None



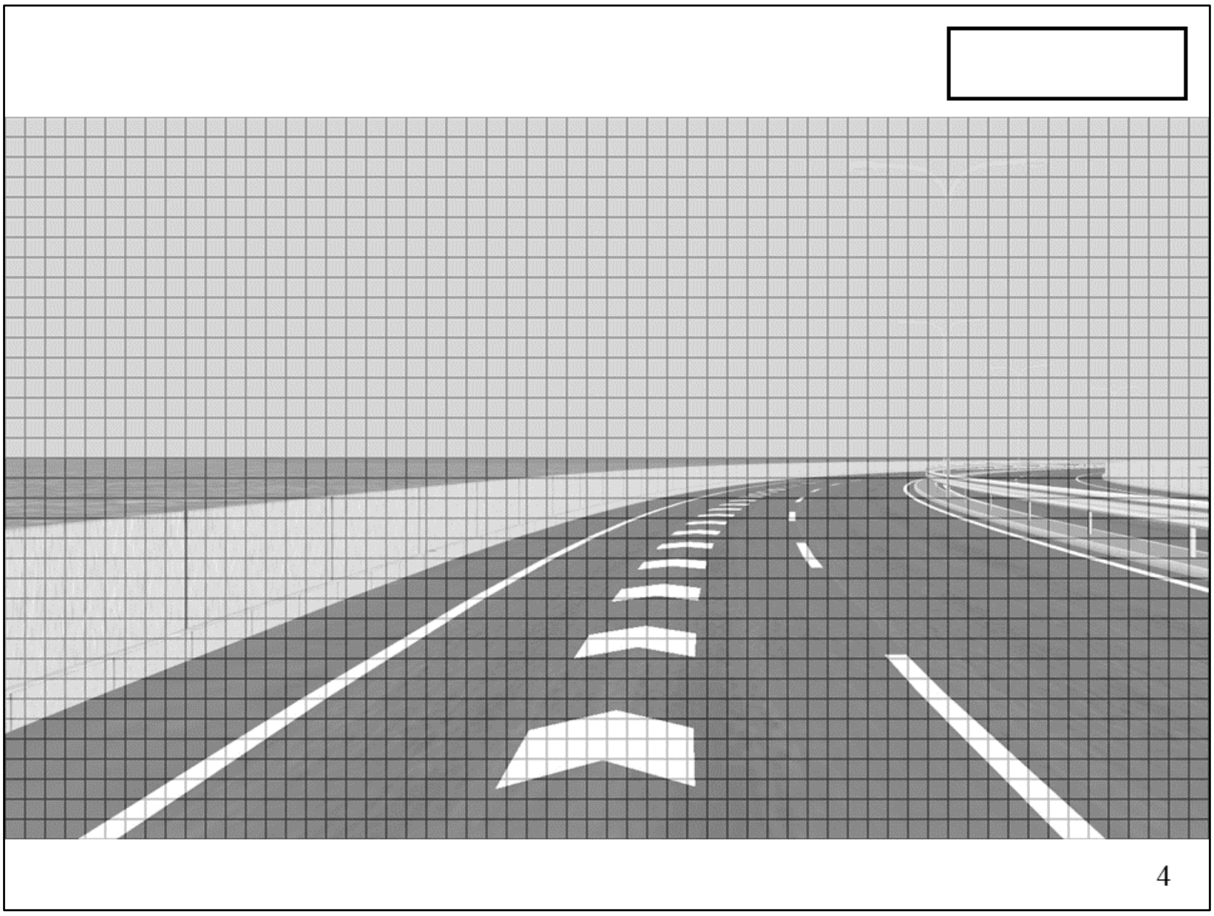
Parallelogram Edge Line



Wide Chevron



Narrow Chevron



Optical Dots

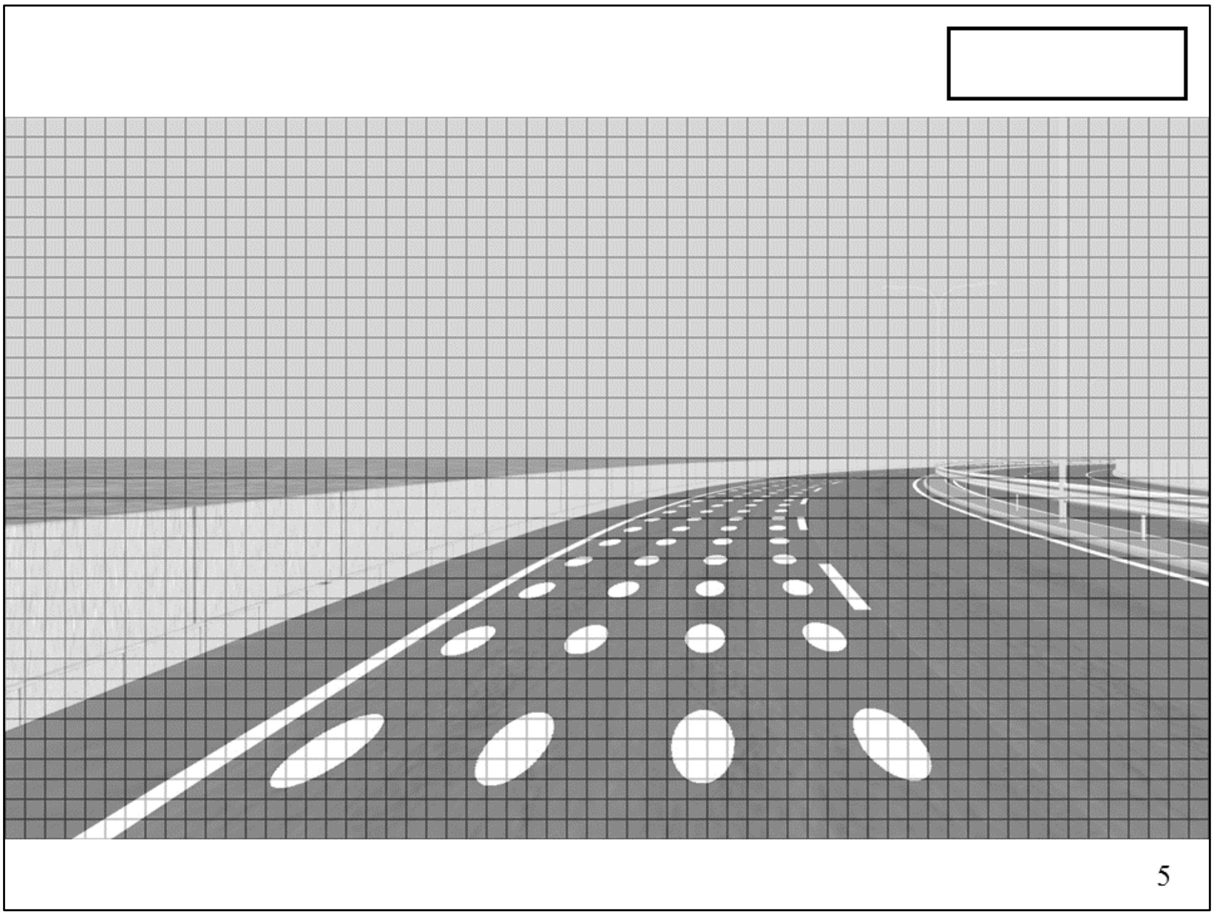


Figure B1. The sheets used for the Grid Image Questionnaire.

None

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
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36	0	0	0	0	1	1	2	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Parallelogram Edge Line

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
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Wide Chevron

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Narrow Chevron

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Optical Dots

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14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	3	4	4	3	2	2	2	4	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	3	3	4	5	7	8	9	6	4	3	2	3	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	5	7	11	13	17	20	17	12	4	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	7	13	12	14	19	19	17	16	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	6	6	8	7	9	13	11	8	6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	4	5	7	6	6	12	11	6	6	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	5	7	7	7	8	11	10	6	6	6	4	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4	4	5	6	8	9	9	8	11	13	10	8	6	9	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	3	3	3	3	6	6	8	9	9	9	12	13	11	9	7	6	4	3	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	3	5	4	4	4	6	6	7	9	8	7	8	12	13	11	9	7	7	7	4	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	5	4	4	4	5	5	6	6	8	6	5	7	9	9	8	7	5	5	4	4	3	3	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	2	2	2	3	3	4	6	5	4	5	5	6	7	6	6	5	3	3	3	4	2	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	3	3	2	3	3	3	5	5	5	4	4	5	6	7	6	6	5	5	4	4	3	3	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	5	4	4	4	5	4	4	6	6	6	5	5	5	6	6	7	6	6	6	6	5	5	5	5	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	5	3	4	4	4	5	4	4	6	5	6	5	5	5	6	6	7	6	6	6	5	5	5	5	4	5	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	4	3	2	3	4	4	5	5	4	6	5	5	5	5	5	5	6	6	7	6	6	5	5	5	4	4	3	3	4	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	2	2	2	2	3	3	4	4	4	5	5	4	4	4	4	3	5	6	4	4	5	4	3	3	3	3	2	2	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	3	3	3	4	4	3	3	3	2	2	3	4	3	3	3	3	3	3	3	3	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	3	2	2	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure B2. Raw data from the Grid Image Questionnaire. Each number in the boxes refers to the total number of participants who circled the point.