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Visibility Assessment Using Driving Video Images Recorded by Onboard Video Camera

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ABSTRACT

The present study proposes a system for evaluating visibility from the driver's viewpoint using the weighted intensity of power spectrum (WIPS). The present study investigates whether the average weighted intensity of power spectrum (WIPS) determined from driving video images recorded by onboard video camera can be used to identify poor visibility conditions on the road ahead by comparing WIPS values with subjective visibility evaluations of the same driving video images. A total of 39 video clips of driving, each 10 seconds long, selected from large number of clips were presented to 12 participants, who responded to a questionnaire on their subjective evaluation of visibility on the road ahead. The WIPS values were found to be consistent with the subjective visibility assessments. The meteorological visibility optical range values were found to not correspond to subjective visibility evaluations. It is supposed that the WIPS values indicate visibility on the road ahead and that WIPS would be preferable to meteorological optical range as an index of visibility.

INTRODUCTION

Visibility information along the whole highway allows road maintenance managers to better operate and maintain roads under adverse conditions. Road maintenance agencies in Hokkaido, Japan, have been using road patrols several times per day during severe weather conditions. Such patrols give reliable visibility information that assists in maintaining driving safety on highways. Therefore, we have developed a system for monitoring visibility accurately and widely for the entire length of the highway. Previously, vehicle-mounted visibility meters were used to evaluate the visibility on the road ahead as perceived by the driver. Nagata et al. (1) proposed a road visibility measuring system that uses still images recorded by an onboard video camera to identify poor visibility on the road ahead. They investigated whether the weighted intensity of power spectra (WIPS) value determined from still images recorded by the onboard video camera can be used to identify poor visibility during driving. The changes in WIPS values were found to correspond roughly in time to changes in visibility meter values.

A system for monitoring visibility accurately and easily evaluated by the driver's eye view is required. Several methods of assessing visibility from still images have been studied (2–7). Hagiwara et al. (8) proposed a method for identifying poor visibility under adverse weather conditions by processing CCTV digital images. The magnitude of the WIPS value represents the difference in spatial frequencies within the image based on the human contrast sensitivity function. Hagiwara proposed WIPS as a way of using images to quantify poor visibility. Nagata et al. (9) conducted subjective assessments of road images taken by CCTV cameras. They examined the amount of variation in subjective estimations of road conditions from digital images and how closely the estimated visibility for a given road image correlated with the WIPS for that image. Assessments of daytime images had little variation among participants and correlated closely with WIPS. Feasibility studies in the daytime during the 2005-2006 winter and the 2006-2007 winter were performed on National Route 230 and National Route 231 in Japan (10). Using stored road visibility data, WIPS values were found to correspond closely with subjective visibility evaluations for the same road images.

Thus, we propose a system for using WIPS to evaluate the visibility from the driver’s perspective. The present study investigates whether the WIPS determined from driving video images recorded by onboard video camera can be used to identify poor visibility conditions on the road ahead by comparing WIPS values with subjective visibility evaluations of the same driving video images. In the present study, we also compared the subjective visibility evaluation estimated by drivers from driving video images with the meteorological optical range measured by a vehicle-mounted visibility meter.

DATA COLLECTION

Measurements on a Highway under Low-Visibility Conditions

On several occasions, we measured the meteorological optical range while recording the driving video image under severe visibility conditions in the daytime during two months of the 2017-2018 winter outside of Sapporo City in Hokkaido, Japan. An instrumented vehicle installed with a vehicle-mounted visibility meter (Figure 1) was used for measurements.

Meteorological Optical Range (MOR)

MOR is recorded by the vehicle-mounted visibility meter at 150 cm high. This compact forward-scatter visibility sensor (Figure 1) was developed by Meisei Electric Co., Ltd. With a measurement range of 20 to 2,000 meters, the Meisei Visibility Sensor TZF-31A offers reliable visibility measurement in snowfall and snowstorms. The system outputs a value of 2,000 meters when the MOR value exceeds 2,000 meters. The sampling rate is 10Hz. The present study uses the MOR value averaged for each second.

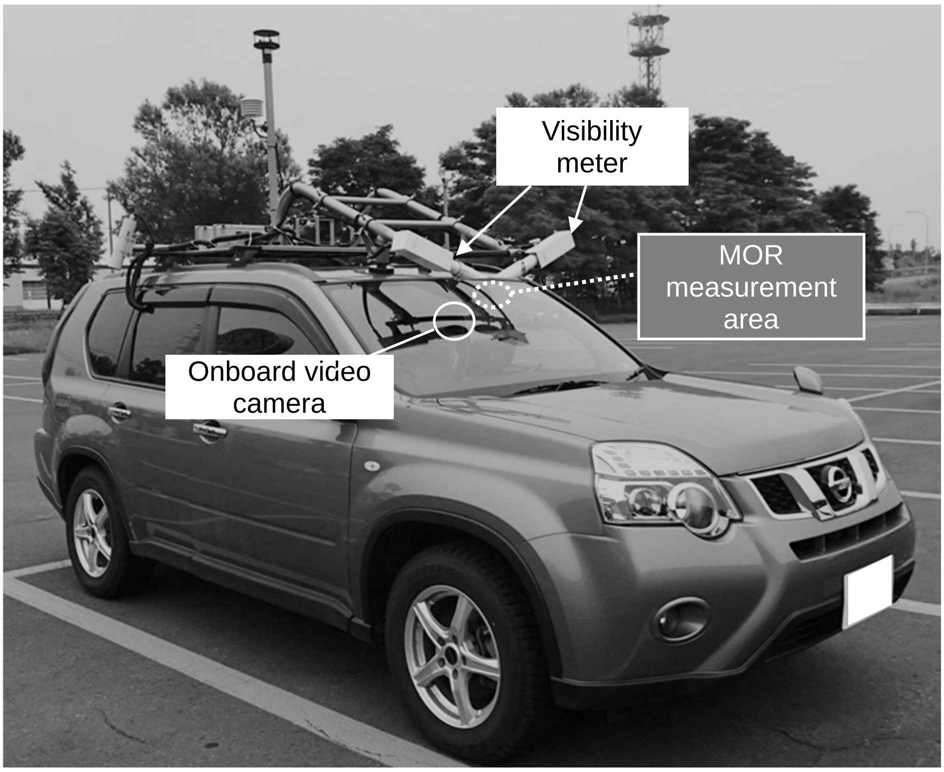

FIGURE 1 The vehicle installed with a vehicle-mounted visibility meter and an onboard video camera

Driving Video Images

The driving video images were recorded by an onboard video camera installed at center of the vehicle between the driver and the co-driver at 130 cm high. The onboard video camera is Driving Pro 200, developed by Transcend Co., Ltd. The recorded video image was 1920×1088 pixels recorded at 29 frames per second.

In the present study, a 10-second driving video clip (hereinafter: a clip) was presented to the drivers, and the drivers completed a questionnaire about the visibility conditions on the road ahead. The driving video clip recorded from 15:07:40 to 15:22:30 on 26 January 2018 was selected from several clips in this study because this clip included conditions in which the visibility ranged from 50 to 500 meters. We created one 10-second video clip for each successive 10 seconds of 890 clips from 15-minute driving videos. A total of 890 clips were created. It was thought that the assessment of subjective visibility in the clips would be influenced by the presence of leading vehicles, oncoming vehicles, sharp curves ahead, and stops at intersections. After clips that included these influences were removed, 267 clips of 10 seconds each remained.

Calculating WIPS for each 10-second clip

Figure 2 shows process for calculating the WIPS value for each clip. First, 10 still images per second were automatically captured from the clip. If a still image included a wiper blade, the experimenter manually selected the nearest still image without a wiper blade. Each still image was halved in size from 1920×1088 pixels to 960×544 pixels. Second, a two-dimensional image of 256×256 pixels was cropped from the center of each still image. Third, the grayscale intensity of each pixel was calculated from the intensities of the red-green-blue (RGB) components recorded in the two-dimensional image of 256×256 pixels. The grayscale intensity ranges from 0 to 255. Fourth, the image was broken down into sinusoidal gratings of different spatial frequencies using two-dimensional fast Fourier transform (FFT). The power spectrum value computed by FFT corresponds to the amplitude of the spatial frequency for each cycle per degree. At the final step, the power spectrum intensities in the range of 1.5 to 18 cycles per degree were summarized. In this study, the average of 10 WIPS values per clip was calculated. Under clear conditions, the power spectra for each spatial frequency component of the road image are great and the WIPS value is large. Under poor visibility conditions, such as those in fog or snow, the power spectra are small and WIPS value is small.

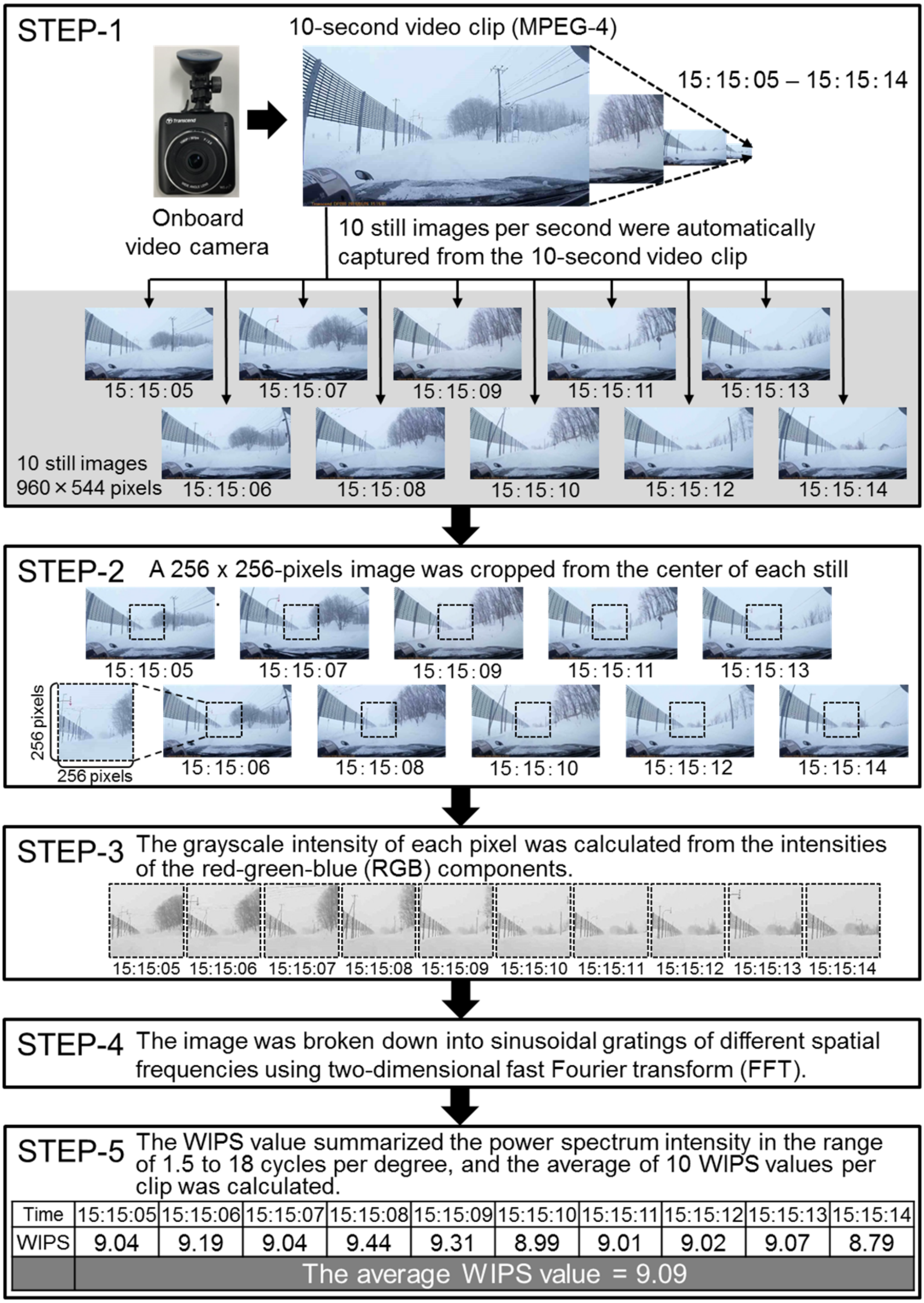

FIGURE 2 The five steps in calculating the WIPS value for each 10-second video clip

COMPARISON OF WIPS AND SUBJECTIVE VISIBILITY EVALUATIONS

Eighteen clips used in experiment, classified into six ranges based on the average WIPS value

The average WIPS values for the 267 clips ranged from 6.83 to 9.12. The average WIPS values were classified into six WIPS ranges: less than 7.0, 7.0 - 7.5, 7.5 - 8.0, 8.0 - 8.5, 8.5 - 9.0 and greater than 9.0. The numbers of clips corresponding to each range above are 13, 29, 51, 89, 56 and 29, respectively. The average MOR values for the 267 clips ranged from 109 meters to 716 meters. Three clips were assigned to each WIPS range: a clip of the minimum MOR for that range, the median MOR for that range and the maximum MOR for that range. Then, in the experiment, the 18 clips listed in Table 1 were evaluated.

Twenty one clips used in the experiment, classified by seven ranges based on the average MOR value

The average MOR values for the 267 clips ranged from 109 meters to 716 meters. The average MOR values were classified into seven ranges: $10^{2.0}$ t $10^{2.1}$ m (100 - 126 m), $10^{2.2}$ - $10^{2.3}$ m (158 - 200 m), $10^{2.3}$ - $10^{2.4}$ m (200 - 252 m), $10^{2.4}$ - $10^{2.5}$ m (252 - 316 m), $10^{2.5}$ - $10^{2.6}$ m (316 - 398 m) and greater than $10^{2.6}$ m (greater than 398 m). The number of clips in each range is 9, 17, 19, 72, 83, 43 and 24, respectively. The average WIPS values for the 267 clips ranged from 6.83 to 9.12. Three clips were assigned to each MOR range: a clip of the minimum WIPS for that range, the median WIPS for that range and the maximum WIPS for that range. Then, in the experiment, the 21 clips listed in Table 2 were evaluated.

TABLE 1 The 10-second video clips classified by the six WIPS ranges

No.	WIPS range	Number of data	Type of MOR value	10-second average of MOR values	Time of video image	10-second average of WIPS values
1	less than 7.0	13	Maximum	162 m	15:08:07 - 15:08:16	6.94
2			Median	191 m	15:08:02 - 15:08:11	6.85
3			Minimum	224 m	15:07:58 - 15:08:07	6.93
4	7.0 - 7.5	29	Maximum	167 m	15:08:08 - 15:08:17	7.02
5			Median	257 m	15:08:45 - 15:08:54	7.21
6			Minimum	400 m	15:07:40 - 15:07:49	7.50
7	7.5 - 8.0	51	Maximum	109 m	15:17:24 - 15:17:33	7.74
8			Median	222 m	15:08:30 - 15:08:39	7.85
9			Minimum	371 m	15:07:41 - 15:07:50	7.55
10	8.0 - 8.5	89	Maximum	127 m	15:20:15 - 15:20:24	8.03
11			Median	303 m	15:18:21 - 15:18:30	8.03
12			Minimum	717 m	15:12:53 - 15:13:02	8.36
13	8.5 - 9.0	56	Maximum	156 m	15:16:29 - 15:16:38	8.60
14			Median	284 m	15:13:56 - 15:14:05	8.78
15			Minimum	520 m	15:18:11 - 15:18:20	8.55
16	greater than 9.0	29	Maximum	284 m	15:14:26 - 15:14:35	9.03
17			Median	359 m	15:14:38 - 15:14:47	9.02
18			Minimum	447 m	15:15:16 - 15:15:25	9.00

TABLE 2 The 10-second video clips classified by the seven MOR ranges

No.	MOR range	Number of data	Type of WIPS value	10-second average of WIPS values	Time of video image	10-second average of MOR values
1	$10^{2.0}$ - $10^{2.1}$ m (100 - 126 m)	9	Maximum	7.69	15:17:23 - 15:17:32	119 m
2			Median	7.80	15:17:28 - 15:17:37	122 m
3			Minimum	7.92	15:20:13 - 15:20:22	122 m
4	$10^{2.1}$ - $10^{2.2}$ m (126 - 158 m)	17	Maximum	7.59	15:17:22 - 15:17:31	129 m
5			Median	8.09	15:20:16 - 15:20:25	140 m
6			Minimum	8.60	15:16:29 - 15:16:38	156 m
7	$10^{2.2}$ - $10^{2.3}$ m (158 - 200 m)	19	Maximum	6.83	15:08:10 - 15:08:19	180 m
8			Median	7.88	15:17:16 - 15:17:25	161 m
9			Minimum	8.34	15:20:20 - 15:20:29	197 m
10	$10^{2.3}$ - $10^{2.4}$ m (200 - 252 m)	72	Maximum	6.88	15:08:01 - 15:08:10	201 m
11			Median	7.63	15:08:29 - 15:08:38	222 m
12			Minimum	8.59	15:20:43 - 15:20:52	223 m
13	$10^{2.4}$ - $10^{2.5}$ m (252 - 316 m)	83	Maximum	7.02	15:07:57 - 15:08:06	265 m
14			Median	8.04	15:18:22 - 15:18:31	282 m
15			Minimum	9.07	15:14:33 - 15:14:42	315 m
16	$10^{2.5}$ - $10^{2.6}$ m (316 - 398 m)	43	Maximum	7.39	15:08:43 - 15:08:52	326 m
17			Median	8.25	15:15:24 - 15:15:33	343 m
18			Minimum	9.12	15:15:04 - 15:15:13	397 m
19	greater than $10^{2.6}$ m (greater than 398 m)	24	Maximum	7.50	15:07:40 - 15:07:49	400 m
20			Median	8.36	15:12:53 - 15:13:02	717 m
21			Minimum	9.09	15:15:07 - 15:15:16	418 m

Participants

Table 3 lists the attributes of the 12 participants. All were licensed to drive in Japan, and all drove at least once a month in winter. They have not participated in surveys or analyses of road visibility, nor did they receive information regarding the experiment prior to the experiment. At the beginning of experiment, the experimenter spent 20 minutes explaining the schedule, the experimental overview and the visibility evaluation tasks to be performed during the experiment, the risks of the experiment, the cancellation policy and emergency procedures. Once the explanation was complete, participants gave written informed consent of participation. No individual declined to participate. The research methodology was approved by the Ethical Review Committee for Research with Human Subjects in the Engineering Course of Hokkaido University, Japan.

TABLE 3 The attributes of the 12 participants

Group	No.	Sex	Age	Driving frequency	Vision correction
Group 1	1	M	24	Monthly	Glasses
	2	M	24	Weekly	None
	3	M	23	Monthly	Glasses
	4	M	21	Monthly	Contact lens
Group 2	5	M	54	Weekly	Glasses
	6	M	50	Daily	Glasses
	7	F	45	Weekly	Glasses
	8	M	30	Weekly	Glasses
Group 3	9	M	63	Daily	Glasses
	10	F	42	Daily	Glasses
	11	M	38	Weekly	Glasses
	12	F	38	Weekly	Glasses

Evaluation Sheets

Each clip was evaluated according to the three subjective rating scales shown in Figure 3: the subjective visibility scale (SVS), the driving comfort scale (DCS) and the visibility-range scale (VRS). The SVS is a measure of visibility conditions whereby participants judge the visibility of the road ahead by viewing the clip. The DCS is a measure of subjective driving comfort that is based on viewing the clip. The VRS is a measure of visibility conditions whereby participants judge the visibility range of the road ahead from a presented clip. SVS ranged from the low of 1 (“Not visible”) to the high of 7 (“Visible”). DCS ranged from the low of 1 (“Uncomfortable”) to the high of 7 (“Comfortable”). VRS ranged from the low of 1 (“Visibility range of less than 50 m”) to the high of 7 (“Visibility range of more than 500 m”).

Experimental Design and Procedure

The experiment was carried out in a conference room of the Hokkaido Development Engineering Center. The participants were divided into the three groups shown in Table 3. Before the experiments, the participants were instructed on how to assess the visual conditions of the clip according to the three scales shown in Figure 3. The experiment took about one hour per group. Table 4 shows the sequence of six tests per group. In each test, the clips were shown randomly on a screen 0.9 m in height by 1.7 m in width to subjects seated 3.4 m in front of the screen. Each test took around 5 minutes. After viewing each clip, the participants were asked to mark their ratings on an assessment sheet.

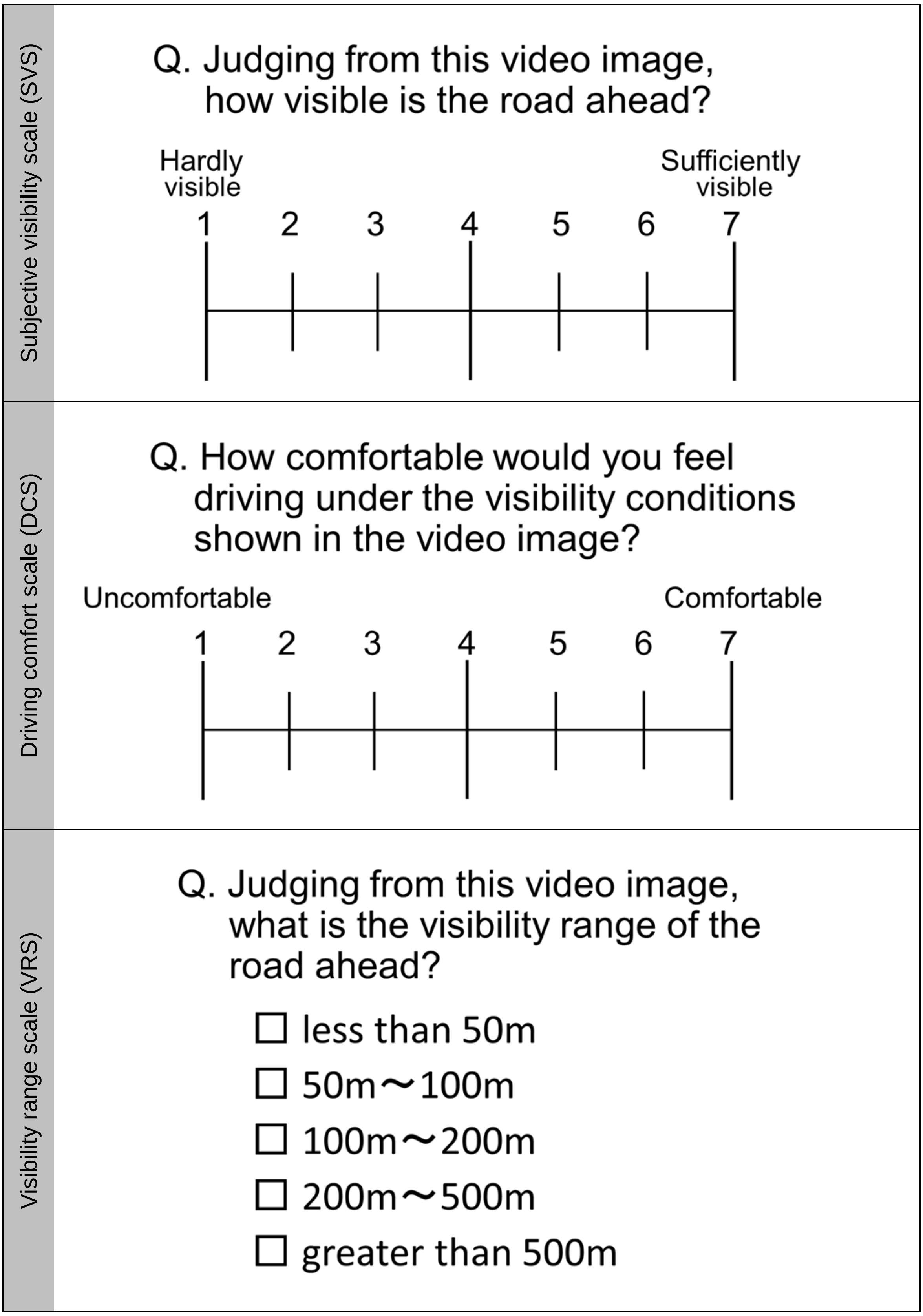

Figure 3 The assessment sheets for the experiments

TABLE 4 Order of the three assessment runs for each group in the experiments

Group	No.	10-second video clips	Assessment sheets
Group 1	1	10-second video clips classified by 6 WIPS ranges	Subjective visibility scale (SVS)
	2		Driving comfort scale (DCS)
	3		Visibility range scale (VRS)
	10-minute break		
	4	10-second video clips classified by 7 MOR ranges	Visibility range scale (VRS)
	5		Driving comfort scale (DCS)
	6		Subjective visibility scale (SVS)
Group 2	1	10-second video clips classified by 6 WIPS ranges	Driving comfort scale (DCS)
	2		Visibility range scale (VRS)
	3		Subjective visibility scale (SVS)
	10-minute break		
	4	10-second video clips classified by 7 MOR ranges	Subjective visibility scale (SVS)
	5		Visibility range scale (VRS)
	6		Driving comfort scale (DCS)
Group 3	1	10-second video clips classified by 6 WIPS ranges	Visibility range scale (VRS)
	2		Subjective visibility scale (SVS)
	3		Driving comfort scale (DCS)
	10-minute break		
	4	10-second video clips classified by 7 MOR ranges	Driving comfort scale (DCS)
	5		Subjective visibility scale (SVS)
	6		Visibility range scale (VRS)

RESULTS

Subjective visibility evaluations for the 10-second video clips classified by the six WIPS ranges

The results of subjective visibility evaluation using the clips classified by the six WIPS ranges from Table 1 are shown in Figure 4. Responses for each WIPS range totaled 36. According to Figure 4(A), the SVS value decreased proportionally to decreases in the WIPS value. The percentage of participants who gave the low rating (“SVS of 1 or 2”) was 0% for the clips with high WIPS values, i.e., WIPS of greater than 8.5. However, the percentage of participants who gave the low rating (“SVS of 1 or 2”) was high for the clips with low WIPS values, i.e., WIPS of less than 7.5. In Figure 4(B), the DCS value indicates a similarly proportional relation to that between WIPS value and DCS value. The DCS value decreases proportionally to decreases in the WIPS value. Figure 4(C) shows the percentage of participants choosing each VRS value for each of the six WIPS ranges. The VRS value decreases proportionally to decreases in the WIPS value. The percentage of participants who gave the low VRS rating (“less than 100 m”) was low for the clips with high WIPS values, i.e., WIPS of greater than 8.0. However, the percentage of participants who gave the low VRS rating (“less than 100 m”) was over 50% for the clips with low WIPS values, i.e., WIPS of less than 7.5.

Subjective visibility evaluation for the 10-second video clips classified by the seven MOR ranges

The results of subjective visibility evaluation using the clips classified by the seven MOR ranges from Table 2 are shown in Figures 5. Responses for each WIPS range totaled 36. Figure 5(a) shows the relationship between the SVS value and the WIPS value. This relationship was unclear. The 200-m to 252-m interval of MOR shows the greatest percentage of participants who gave the “SVS of 1 or 2”. The 158-m to 200-m interval of MOR shows the second-greatest percentage of participants who gave the “SVS of 1 or 2”. When the MOR range was 100 m to 126 m or 126 m to 158 m, the percentage of participants who gave the lowest rating (“SVS of 1”) was 0%. The DCS rating in Figure 5(b) and the VRS rating in Figure 5(c) have similar composition ratios to those for SVS. The subjective visibility evaluations for the clips as classified by the seven MOR ranges were not consistent with the three types of subjective visibility evaluations.

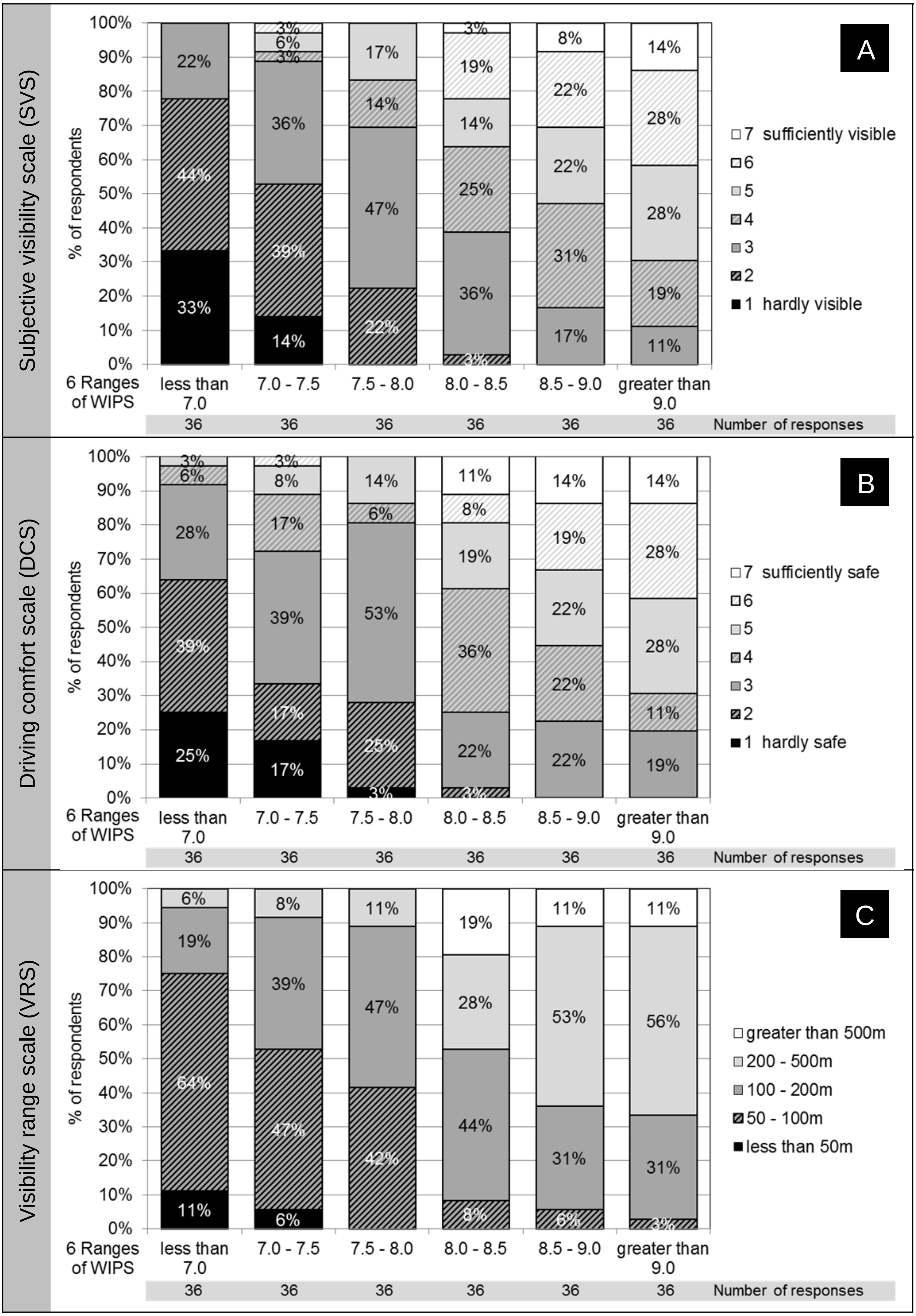

FIGURE 4 SVS, DCS and VRS values for the 10-second video clips classified by the six WIPS ranges

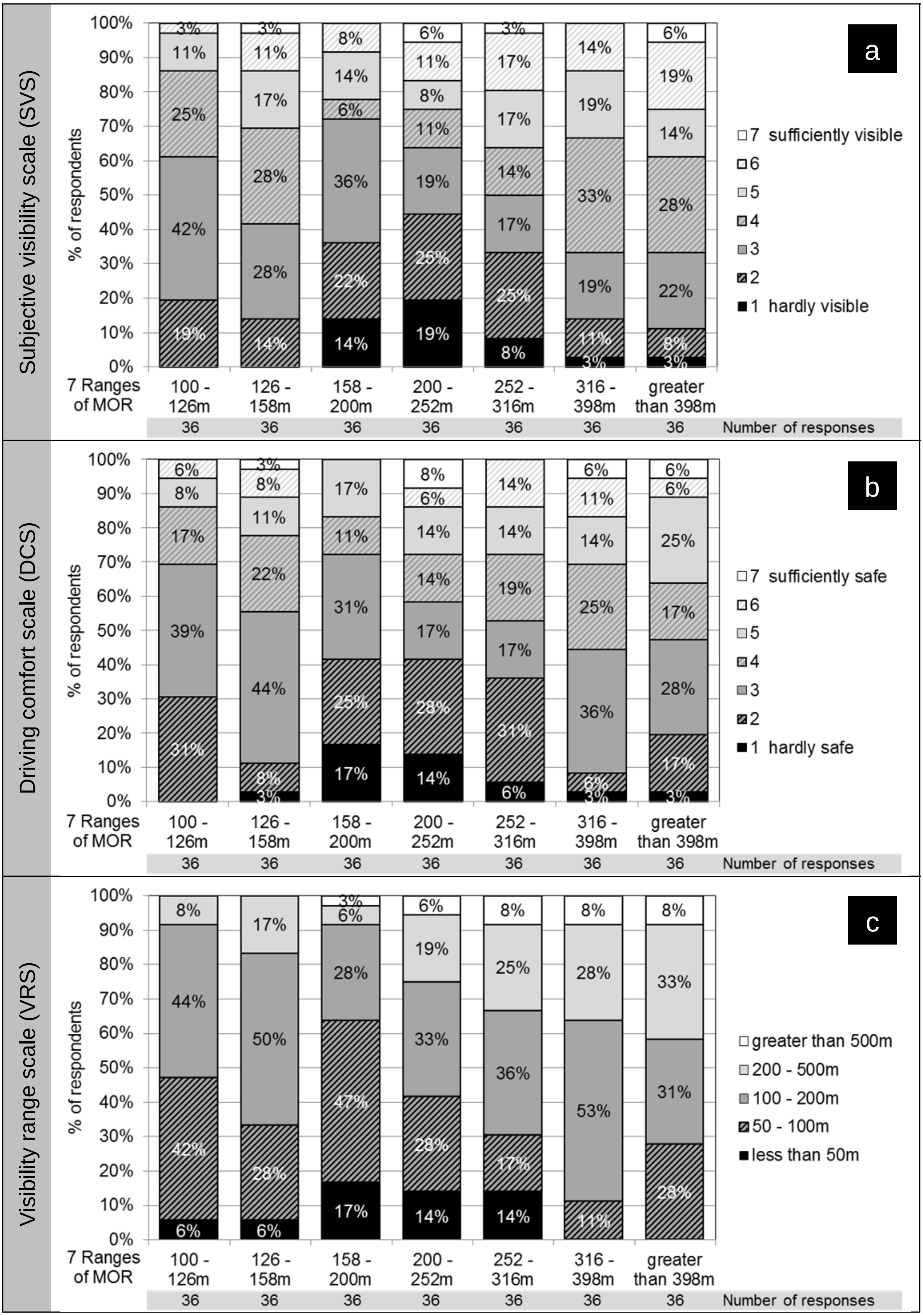

FIGURE 5 SVS, DCS and VRS values for the 10-second video clips classified by the seven MOR ranges

Results of comparison between the average of subjective visibility evaluations (SVS, DCS) and the average WIPS value

The scatterplots in Figure 6(A) and Figure 6(B) show the results of the experiment using the 18 clips listed in Table 1. The scatterplots in Figure 6(a) and Figure 6(b) show the results of the experiment using the 21 clips listed in Table 2. Figure 6(A) and Figure 6(a) show scatterplots of the relationship between the average SVS values and the average WIPS value. Each of the two determination coefficients in Figure 6(A) and Figure 6(a), which plot WIPS values versus SVS values, exceeds 0.9, and the parameters of the estimated regression equations are similar between the two scatterplots. Figure 6(B) and Figure 6(b) show scatterplots of the relationship between the average DCS values and the average WIPS values. Each of the two determination coefficients in Figure 6(B) and Figure 6(b), which plot WIPS values versus SVS values, are around 0.9, and the parameters of the estimated regression equations are similar between the two scatterplots. The determination coefficients for DCS are smaller than those for SVS.

Results of comparison between the average of subjective visibility evaluations (SVS, DCS) and the average MOR value

The scatterplots in Figure 7(A) and Figure 7(B) show the results of the experiment using the 18 clips listed in Table 1. The scatterplots in Figure 7(a) and Figure 7(b) show the results of the experiment using the 21 clips listed in Table 2. Figure 7(A) and Figure 7(a) show scatterplots of the relationship between the average SVS values and the average MOR values. Figure 7(B) and Figure (b) show scatterplots of the relationship between the average DCS values and the average MOR values. The determination coefficient for each of these scatterplots is less than 0.3.

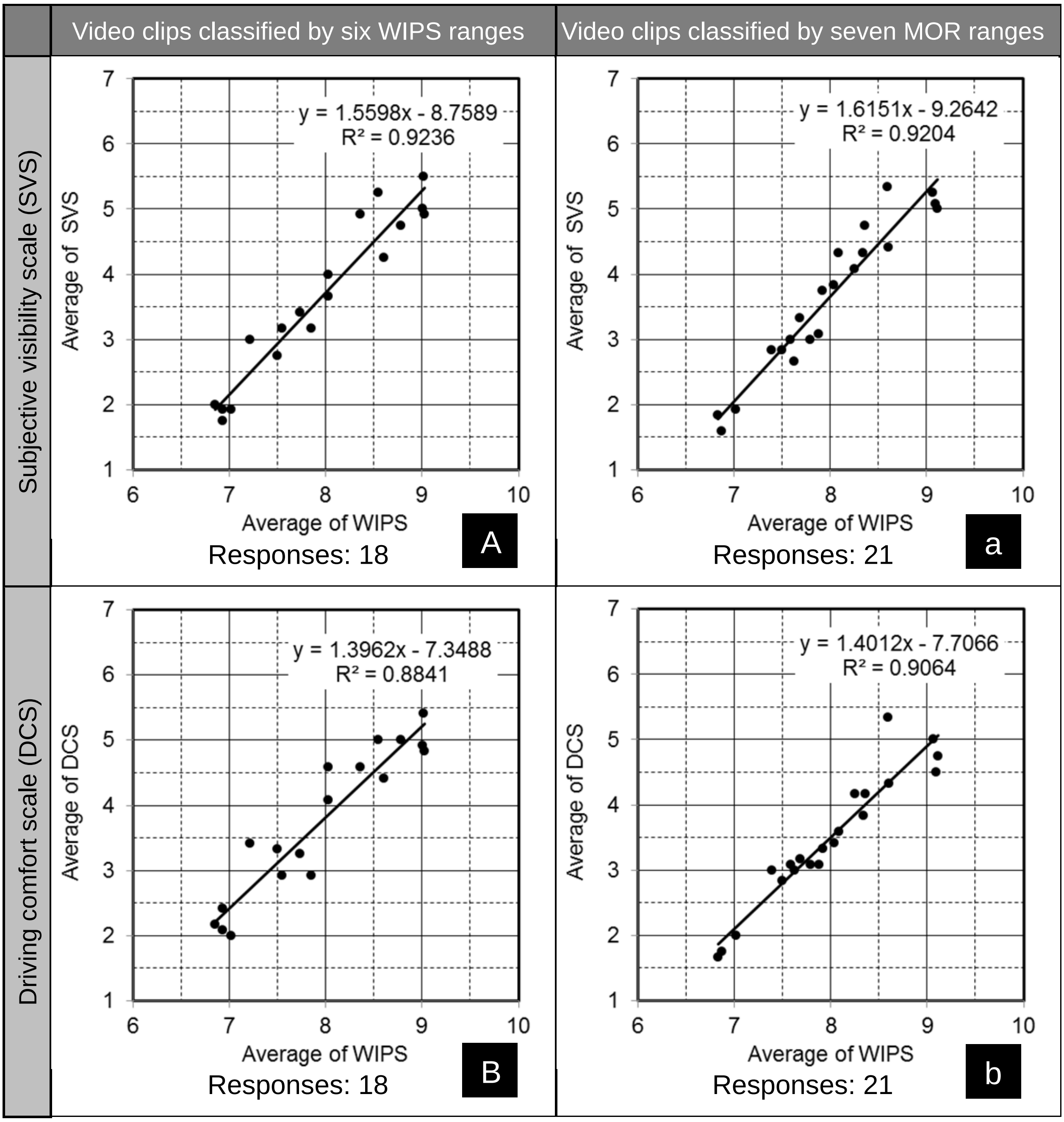

FIGURE 6 Scatterplots of subjective visibility evaluations for the 10-second video clips versus average WIPS values

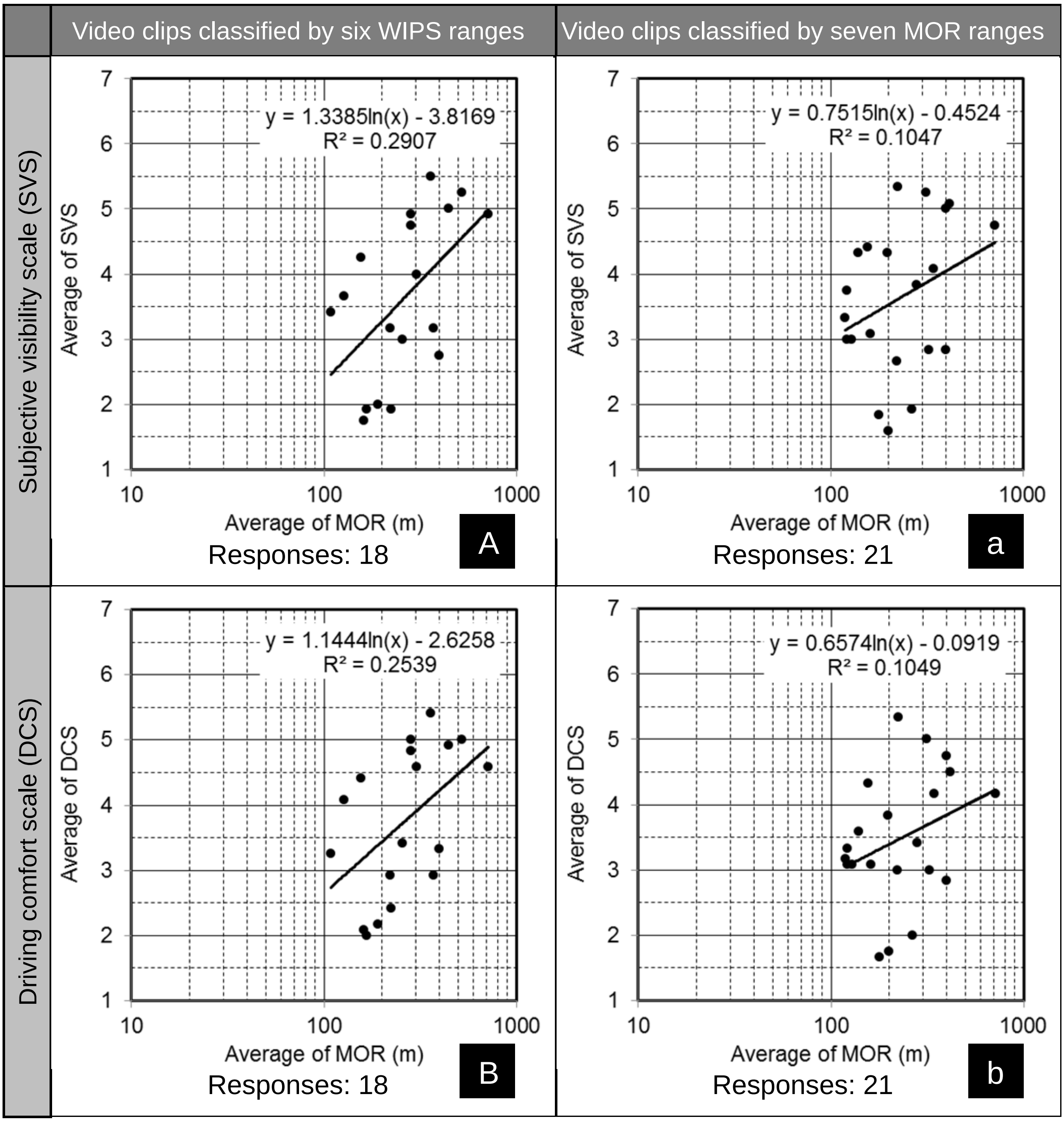

FIGURE 7 Scatterplots of subjective visibility evaluations for the 10-second video clips versus average MOR values

DISCUSSION AND CONCLUSIONS

The present study investigated whether the average weighted intensity of power spectrum (WIPS) determined from driving video images recorded by onboard video camera could be used as an indicator of poor visibility conditions on the road ahead by comparing the WIPS values with subjective visibility evaluations of the same driving video images. The meteorological optical range (MOR) and the driving video image of the road head were simultaneously recorded in the daytime under severe visibility conditions in winter. A total of 267 video clips, each 10-seconds long, were created from the recorded diving video images, and the WIPS value was calculated for each clip. In the laboratory, 39 video clips selected from 267 clips were presented to the 12 participants, and they had to complete a questionnaire about the visibility conditions on the road ahead. From this investigation, the WIPS value was found to be consistent with both the SVS and the DCS value. The MOR value did not consistently correspond to the SVS value nor to the MOR value. It is supposed that the WIPS value could show the visibility level of the road ahead and that it was preferable to the MOR value as an index of visibility.

The WIPS value might represent not only the visibility range immediately in front of the vehicle but also the visibility conditions for the entire scene ahead. Matsuzawa et al. (11) revealed that the visibility as perceived by drivers during blowing snow is affected by the road surface conditions and the surrounding environment (i.e., urban versus suburban). When the background of the road ahead has few objects within the image, the driver might judge the visibility to be poor even when the visibility conditions are not so poor. WIPS values determined from images recorded by onboard camera might indicate visibility levels that correspond to those perceived by drivers.

A method is needed whereby visibility can be monitored easily, accurately and along the entire length of the highway, so that a smart system for winter highway maintenance can be developed. The system proposed in the present study might be feasible for evaluating the visibility easily and accurately from the driver’s-eye view using WIPS. Probe vehicles of determine visibility conditions based on WIPS values of the road travel environment. However, WIPS values of images with a large number of objects should become large whereas visibility conditions are poor. We should propose a reliable and feasible estimation method for calculating WIPS values using images recoded by the onboard camera.

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