Accident Analysis and Prevention 42 (2010) 1003–1008

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Effects of color scheme and message lines of variable message signs on driver performance

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ARTICLE INFO

Article history:
Received 12 April 2009
Received in revised form 1 September 2009
Accepted 7 December 2009

Keywords:
Variable message signs (VMS)
Color scheme
Message lines

ABSTRACT

The advancement in variable message signs (VMS) technology has made it possible to display message with various formats. This study presented an ergonomic study on the message design of Chinese variable message signs on urban roads in Taiwan. Effects of color scheme (one, two and three) and number of message lines (single, double and triple) of VMS on participants' response performance were investigated through a laboratory experiment. Results of analysis showed that color scheme and number of message lines are significant factors for participants' response time to VMS. Participants responded faster for two-color than for one- and three-color scheme. Participants also took less response time for double line message than for single and triple line message. Both color scheme and number of message lines had no significant effect on participants' response accuracy. The preference survey after the experiment showed that most participants preferred two-color scheme and double line message to the other combinations. The results can assist in adopting appropriate color scheme and number of message lines of Chinese VMS.

1. Introduction

Variable message signs (VMS) are programmable traffic control devices that are located at key decision points on the motorway and trunk road network. These signs offer an increase in traffic safety by their ability to deliver messages to motorists for warning of hazards ahead such as traffic congestion, accidents, and lane closures. The information is most often displayed in real-time and can be controlled either from a remote centralized location or locally at the site. With more sophisticated technologies, VMS are gaining widespread uses in intelligent transportation systems (ITS). They are commonly installed on full-span overhead sign bridges, post-mounted on roadway shoulders, and overhead cantilever structures. They have become a new trend in roadway signs.

The majority of early studies on VMS focus on evaluating the rates of compliance, either by using survey or via observational studies (Bonsall and Palmer, 1999). A survey of more than 500 motorists in the Washington, DC area assessed motorists' attitudes toward VMS and the effects of demographic characteristics on these attitudes (Benson, 1996). In the responses to the survey question regarding how often VMS influenced their driving, half the respondents replied "often", 40% answered "occasionally", and the others indicated "not at all". The interview survey conducted in London revealed that 97% of drivers were aware of the existence of VMS, 62% completely understood the information presented on VMS, 84% considered the information presented to be useful, and 46% had diverted in response to the travel time information on at least one occasion (Chaterjee et al., 2002). The research on travelers' response to VMS in Paris concluded that VMS alone could affect vehicle diversion significantly. VMS were most effective when displayed during periods of increasing congestion, the longer the queue length posted in VMS, the more vehicles diverted (Yim and Ygnance, 1996). Lai and Yen (2004) employed questionnaires to investigate drivers' attention, preference and response to VMS on freeways in Taiwan. The results indicated that 69.23% of drivers were aware of the existence of VMS while driving on freeway. Display characteristics of VMS, such as font type, font color, and display format affected drivers' attention and response significantly. It also found that demographic variables, such as age, gender and education were also significant factors for drivers' preference and response to VMS.

In the design and display of VMS, many factors can affect their effectiveness. They include size of VMS (board size and font size), location (height and viewing angle), color (background and foreground), display (words, sequence, and format), etc. Proper selections of these factors and their levels are very important. Inaccurate or poorly formatted VMS can easily confuse or mislead motorists, and not allow them to read and understand the message within a short time (Wang and Cao, 2003). Armstrong and Upchurch (1994) conducted a field study in Phoenix, Arizona on human factors design considerations such as legibility distance,

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doi:10.1016/j.aap.2009.12.002

target value, and viewing comfort for fiber-optic and LED VMS on freeways. It concluded that the optimum number of words contained in a message varied with the VMS technology, the lighting conditions, and the prevailing traffic speed. For VMS using other technologies or with different character fonts or dimensions, a legibility analysis prior to its implementation should be performed. Since the advancement in VMS technology has made it possible to display message with various formats, there is a need to study drivers' comprehension and response to these recent VMS features.

Color is an important characteristic of visual stimuli that may affect visual performance. Color can be an effective means to improve human–computer communication (Pastoor, 1990). Matthews (1987) found that inappropriate use of color can result in poor performance and a higher incidence of visual discomfort on CRT reading task. Wang and Cao (2003) conducted a laboratory experiment study to evaluate the display formats of variable message signs. It found that the font color significantly affects drivers' response time. Green font color resulted in the shortest response time, while the red color resulted in the longest. Lai (2008) also found that participants responded faster and more accurately for green and yellow font colors than for red to Chinese VMS.

In addition to font color, color scheme is also an important factor that can affect driver performance. Sanders and McCormick (1993) have recommended using a few colors as possible in the design of screen text/background color combination. Too many colors make the display look confused and are distracting. Wickens et al. (1998) indicated that care should be taken to avoid an extensive number of colors. Yang et al. (2005) conducted an ergonomic study to assess drivers' response and preferences to various combinations of VMS messaging features. Both survey and simulation results suggested that tricolor scheme resulted in longest response time than one- and two-color scheme. Amber, green or green-amber combination were the preferred colors. Participants took longer to respond to message containing red.

Number of message line is another factor that may affect driver performance to VMS. Wang and Cao (2005) employed a video-based experimental approach to study participants' response to a variety of portable VMS stimulus message. Results indicated that message with fewer lines were responded to faster in both discretely and sequentially displayed messages. The study of various bilingual VMS configurations on driver behavior conducted by Jamson et al. (2005) found that drivers were able to read one- and two-line monolingual signs and two-line bilingual signs without disruption to their driving behavior. However, drivers significantly reduced their speed in order to read four-line monolingual and four-line bilingual signs, accompanied by an increase in headway to the vehicle in front. The survey conducted by Lai and Yen (2004) at the rest area on freeways in Taiwan showed that drivers preferred one-line (49.68%) and two-line (45.19%) message to three and greater (4.93%).

Most of the investigations of variables concerned with information presentation on VMS have been done within the context of English. The results of some of this research may not be generalized to Chinese VMS information presentation because of significant differences between English and Chinese characters and differences between the conventional methods of reading patterns typical of Western and Chinese cultures. Chinese characters have a completely different structure and appearance. Every Chinese character is a word that has its own meaning and unique appearance. Therefore, reading Chinese characters is a kind of symbol recognition process, whereas recognizing English word is a "spelling" process (Hwang et al., 1988). Because of the completely different recognition process of English and Chinese, the results obtained from studies of English information display in VMS may not be applicable to Chinese information display. The investigation of the effects of information formats in Chinese VMS is needed.

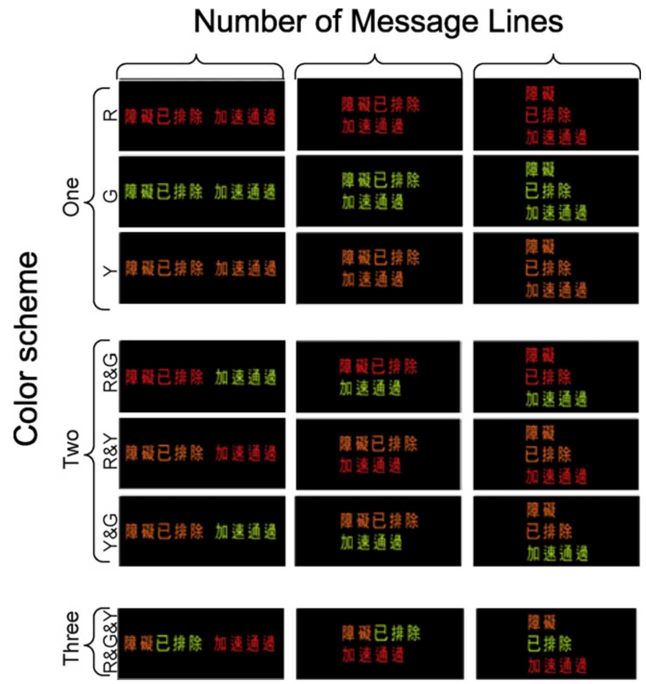

Fig. 1. Examples of VMS messages used in the experiment with the combination of color scheme and umber of message lines. "Y" denotes yellow, "R" denotes red, and "G" denotes green.

Full-span overhead VMS and overhead cantilever VMS are the main kinds of VMS installed on the roadway. Multiple font colors and message lines are used broadly on the overhead cantilever VMS on urban roadways in Taiwan. The main purpose of this study was to investigate the effects of color scheme and number of message lines of overhead cantilever Chinese VMS on driver performance.

2. Method

2.1. Experimental design

This study focused on evaluating the effects of color scheme and message line of cantilever Chinese VMS as viewed by drivers. There were three levels of color scheme: one (green, yellow or red), two (green and yellow, green and red or yellow and red) and three (green and yellow and red). Seven types of color scheme were used in total. Single, double and triple lines of message were used for the variable of number of message lines. These color scheme and message lines all have been used for cantilever VMS on urban roadways in Taiwan. A within-participants design was conducted for the two independent variables. Nine treatment groups represented the combinations of the two within-participants factors of color scheme and number of message lines. Four messages of Chinese VMS were used as stimuli. Each participant went through a total of 84 randomized VMS presentations (that is, 4 messages $\times$ 7 color scheme $\times$ 3 message lines) in each test block. Two successive test blocks were conducted for each participant. Fig. 1 shows examples of VMS messages used in the experiment with the combination of color scheme and message lines.

2.2. Materials

The stimuli used in this study were composed of a sequence of computer-generated cantilever VMS merged with a real drivers' view video. The driving videos were taken with a Sony VDCR-TRV60 digital video camcorder mounted on a tripod and leveled at driver's eye height inside a 2006 Toyota Camry traveling at 50 km/h through a three-lane segment of Wen-xin road in Taichung at about

Table 1
The luminance (L) and CIE chromaticity coordinates (x, y) of the font colors and black background used in this study.

Coordinate	Font color			Background
	Red	Green	Orange	Black
x	.596	.285	.488	.302
y	.381	.583	.443	.304
L (cd/m^2)	35.6	48.3	54.5	.67

Table 2
The four messages on VMS and associated response modes.

Message (in Chinese)	Associated response mode
Red light ahead, slow down (前方號誌紅燈　減速慢行)	Press left pedal
Accident removed, speed up to pass (障礙已排除　加速通過)	Press right pedal
Right lane closed, change to left (外側施工中　靠左行駛)	Turn the wheel to left
Left lane closed, change to right (內側施工中　靠右行駛)	Turn the wheel to right

5:00 p.m. on a sunny day in August 2007. Each stimulus used black as the background color and with a different combination of color scheme and message line for VMS message. On the basis of the findings of Lai (2008), the Chinese font of VMS was presented with Hei-type. The color luminance and Commission Internationale del'Eclairage (CIE) chromaticity coordinates (x, y) of font colors and black background are shown in Table 1. The luminance contrast between message and background is approximately 0.98. Table 2 showed the contents of four messages on VMS and their associated response modes via wheel and pedal.

The VMS stimuli were introduced to appear on the inner lane in a random but controlled manner. It would initially appear at the far end of the video as a small dot as seen in actual driving. The time interval allowed for each VMS presentation was 12 s and would terminate when a response was made during the presentation. The size of each character in the VMS was 0° of visual angle when the VMS just presented, and was about 2° at the end of VMS presentation. Fig. 2 is an example of the VMS message merged with the scene of the virtual driving environment.

2.3. Participants

Thirty university students (15 female and 15 male) who were between 19 and 28 years old (M = 22.31, SD = 1.37) participated in the experiment. All had 0.8 corrected visual acuity or better and normal color vision. Each participant has a valid driver's license and has driving experiences on roadway for one year at least. They were paid for their participation.

Fig. 2. An example scene of the virtual driving environment.

2.4. Apparatus and conditions of workplace

A Topcon Screenscope SS-3 was used to test participants' visual acuity and color vision. The CIE color values were measured with a Minolta color analyzer CA-100. The experiment was conducted in virtual driving environments. A P4 2.4 GHz PC with 1 GB ram was used to process the experimental task program for the participants. A Microsoft side winder force feedback wheel, replacing the steering wheel, was installed in front of the driver's seat of a refitted used car in the ergonomic laboratory. Computer-generated VMS merged with a driver's view video was projected onto a screen (292 cm wide × 220 cm high) in front of the test vehicle through an EPSON EMP-730 projector. The distance between participant and screen was 700 cm. The illumination was about 300 lx which tested at participant's seat and 500 lx at screen. The experimental layout is shown in Fig. 3.

2.5. Task and procedure

A test participant, sitting in the driver's seat of a refitted used car, would see the driving video on the screen with VMS stimuli appearing on inner road lane and gradually increasing in size. The participant was instructed to identify the message presented during each trial by turning the steering wheel with hand or by pressing the pedal with foot to signify her/his comprehension of a specific message. After a response was made, the VMS stimulus

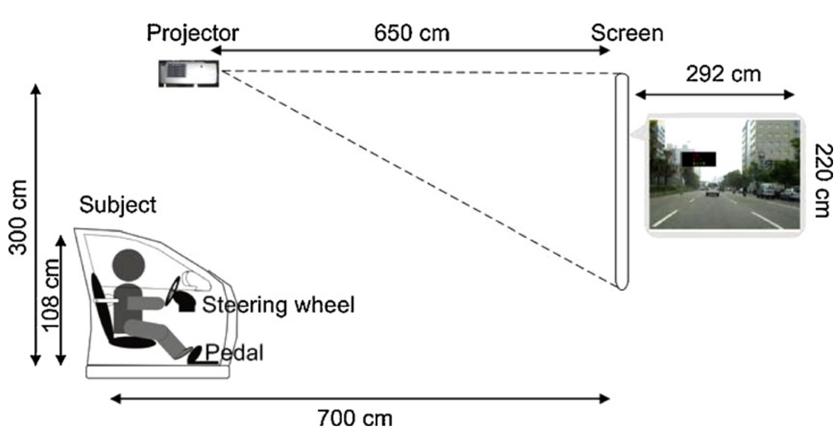

Fig. 3. The experimental layout.

Table 3
Means and standard deviations of response times and correct percentage under levels of independent variables.

Independent variables	Level	n	Response time (s)			Correct percentage (%)	
			Mean	S.D.	Tukey[a]	Mean	S.D.
Color scheme	One	90	7.994	1.059	A	98.36	3.65
	Two	90	7.748	0.989	B	98.97	2.21
	Three	90	8.154	1.008	A	97.83	5.13
Message line	Single	90	7.979	1.014	A	98.34	3.66
	Double	90	7.871	1.043	B	98.65	3.05
	Triple	90	8.044	1.033	A	98.17	4.73

[a] Different letters in Tukey group indicate significant difference at 0.01 level.

disappeared, and the next stimulus would appear after a random elapse between 1 and 3 s. The computer will record participants' response mode and compare to the associated mode that is shown in Table 2. If the response mode was consistent to the associated mode, the response was regarded as a correct response. Participants' response times and correct responses were recorded by the computer automatically.

Before starting the experiment, each participant was briefed with the purpose and procedures of the experiment. In order to prevent visual fatigue, participants were asked not to do any reading tasks for an hour before the experiment. A warm up session was conducted in the beginning to familiarize participants with the response task. With the participants' consent, the actual experiment started. The complete experiment took about one hour. A short survey for the preference of color scheme and number of message lines was given to each participant after the experiment.

2.6. Performance measure and data analysis

The dependent measures collected in this experiment were the response time and correct percentage. Response time was the time between the present of a VMS stimulus and the participants' correct response to the message. Percent correct was 100 times the number of VMS correctly response divided by the total number of VMS. An analysis of variance (ANOVA) was conducted for each of the dependent measures. The factors that were significant were further analyzed using Tukey test to discuss the difference among the factor levels.

3. Results

3.1. Response time

Table 3 shows the means and standard deviations of response times and correct percentage under each level of the independent variables. Results of the analysis of variances for response time have shown that the main effects of color scheme were significant (F (2, 58) = 23.36, p < 0.01). Multiple comparisons using Tukey test demonstrated that two-color scheme had the shortest response time (7.748 s), with one-color scheme next (7.994 s) and three-color scheme the longest (8.154 s). However, there was no significant difference between one-color scheme and three-color scheme. There was also a significant main effects for message lines (F(2, 58) = 16.26, p < 0.01). Tukey test showed that response time for double message line (7.871 s) was shorter than for single (7.979 s) and triple message line (8.044 s).

The interaction of color scheme and message line was not significant on response time. Fig. 4 shows that response time for the two-color scheme was shorter than for the one- and three-color scheme on all levels of number of message lines. The combination of two-color scheme and double line message had the shortest response time, while three-color scheme with triple line message had the longest time.

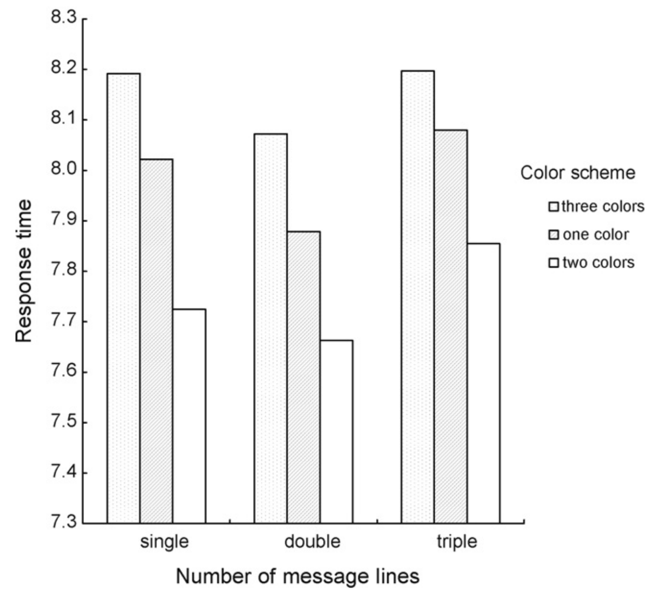

Fig. 4. Response times for each message line at different color scheme.

3.2. Correct percentage

Means and standard deviations of correct percentage under each level of the independent variables are shown in Table 3. The overall correct percentage was 98.39%, a fairly accurate performance considering that the participants' response to color scheme and message line of a stimulus had to be correct for the responses to be registered as accurate. Analysis of variance performed on correct percentage showed no significant effect.

3.3. Preference surveys

The preference data of color scheme and message line from the follow-up experiment survey are summarized in Table 4. It was found that most of the participants preferred the two-color scheme (21/30) and double message line (23/30). A Chi-square test on the preferred fraction indicated that color scheme ($\chi^2(2) = 18.2, p < 0.001$) and number of message lines ($\chi^2(2) = 25.4, p < 0.001$) were all significant difference. The survey results were in accordance with the experiment results.

4. Discussion

4.1. Color scheme

This study investigated the effects of color scheme and number of message lines of Chinese VMS on driver performance. Results showed that color scheme and number of message lines significantly affected participants' response time. Participants responded

Table 4
Questions and responses of the follow-up survey.

Question	Choice	Number	Preferred Fractions
Which kind of VMS color scheme do you prefer?	One	4	$\frac{4}{30}$
	Two	21	$\frac{21}{30}$
	Three	5	$\frac{5}{30}$
Which kind of VMS message line do you prefer?	Single	4	$\frac{4}{30}$
	Double	23	$\frac{23}{30}$
	Triple	3	$\frac{3}{30}$

faster for two-color scheme than one- and three-color scheme. The post preference survey indicated that participants preferred two-color scheme (21/30) to one-color scheme (4/30) and three-color scheme (5/30). These results are partly consistent with the findings of Yang et al. (2005). Their study found that tricolor scheme resulted in longer response time. It is clear that inappropriate use of color can result in poor performance and a higher incidence of visual discomfort (Matthews, 1987). Christ (1975) suggested that color codes were generally better for searching task than most other codes. He also found that color codes were better for identification tasks than were certain other codes, but color codes were generally not as good for such tasks as letter and numerals were (Sanders and McCormick, 1993). In this study, the perception and comprehension of a road VMS can be regard as an identification task. Multiple color scheme VMS presented to drivers may cause a relatively cluttered environment. The superiority of color codes for VMS font might decrease, and lead to the longest response time for three-color scheme.

Furthermore, response time for one-color scheme was longer than for two-color scheme VMS in this study. The result is not consistent with the findings of Yang et al. (2005). Their study showed that amber, green or green-amber combination was the preferred colors, and single amber-colored message resulted in the shortest response time. A possible explanation is the compatible relationship of color codes and message contents of VMS. The message used in the experiment was divided into two parts. The first part described the road event ahead (e.g. “Right lane closed”), and the second part instructed drivers to respond to it (e.g. “Change to left). The use of two-color scheme was compatible to the divided message. Participants can “chunk” message into two entities. The compatible relationship of color and message may result in the less response time for two-color scheme than for one-color scheme. To sum up, this result confirmed the perspectives of Wickens et al. (1998), which showed that effective color coding can present different classes of information in different colors. However, cares should be taken to avoid an extensive number of colors.

4.2. Number of message lines

In this study, number of message lines also affected participants’ response time significantly. Participants responded quickly for double line message than for single and triple line message. The follow-up short survey also showed that participants preferred double line message (23/30) to single (4/30) and triple line message (3/30). The results are similar to the findings of Wang and Cao (2005) and Jamson et al. (2005). Their studies on the number of line of VMS message indicated that participant’s response time increased with the number of lines of relevant text. The disjunction of the message for triple message lines could be the main factor to the longest response time. The message of VMS for single and double line was divided into two parts according to the meaning, whereas the same message for triple line display was divided into three parts. This breaks the connections of message meaning for triple line display. The participants should have to pay more time to chunk the information.

However, participants’ response time for single line message was longer than for double line. This result was not consistent with the study conducted by Wang and Cao (2005) and Jamson et al. (2005). Different message stimulus might be responsible for the inconsistency. First, the number of text of message increased with the number of message line in previous studies, that is, the amount of information unit increased with the message lines. The basic principle of information theory points that choice reaction time is a function of stimulus information (Hyman, 1953). The amount of information unit is less for single line message than for double line message. Participants should interpret and respond to the information for single line more quickly. However, in present study, the message of VMS is identical for each level of message lines. The predominance of single line message disappeared. Furthermore, the length of double line message was shorter than for single line message. Shorter line length is easer to scan than longer ones. The reason for the longer response time for single line may be attributed to the longer line length for single line message.

5. Conclusions

This research investigated the effects of color scheme (one, two and three) and number of message lines (single, double and triple) of VMS on participants’ response performance on urban roads in Taiwan through a laboratory experiment. Results of analysis showed that participants took less response time for double line message than for single and triple line message. Participants also responded faster for two-color than for one- and three-color scheme. Participants responded quickest for the combination of two-color scheme and double line message, while they responded slowest for the three-color scheme with triple line message. The preference survey after the experiment showed that most of participants preferred two-color scheme and double line message to the others. The results can assist in adopting appropriate color scheme and number of message lines of Chinese VMS and in improving the respond performance of drivers on roadway.

The experiment approach employed in the study provides an Ergonomic design consideration to assess the effects of various Chinese VMS design and display factors. It will promote a better understanding about the display of Chinese font color scheme and message lines on VMS in the human/intelligent transportation system interface issues. However, the application of the results should be taken with care because there are some limitations in this study. This study was conducted in a laboratory setting. Participants were asked to respond to a pre-recorded driving video without interacting with real traffic. The circumstances allowed the test participants to put their best effort in the VMS task, where in real-world driving, there are other needs that could demand attentions from the drivers.

Acknowledgements

This research was funded by the National Science Council of Republic of China under contract no. NSC-94-2213-E-167-001. The author would like to thank Wei Ko for his help in conducting experiment.

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