Cognitive Design Features on Traffic Signs

Annie W.Y. Ng and Alan H.S. Chan

***Abstract*—The success of effective communication of traffic sign messages to road users may not only relate to the user characteristics but also the signs themselves. The purpose of this experiment was to examine the cognitive design features of 120 Mainland China traffic signs. The features included familiarity, concreteness, simplicity, meaningfulness, and semantic closeness. Forty-one Hong Kong Chinese engineering undergraduates, who have never taken any driving tests, nor possessed any driving licenses in any places, voluntarily participated in this experiment. For each sign, subjects were asked to give subjective ratings between 0 to 100 points for familiarity (0 = very unfamiliar, 100 = very familiar), concreteness (0 = definitely abstract, 100 = definitely concrete), simplicity (0 = very complex, 100 = very simple), meaningfulness (0 = completely meaningless, 100 = completely meaningful), and semantic closeness (0 = very weakly related, 100 = very strongly related). With the exception of familiarity, the mean ratings on the other four sign features for all signs were above the midpoint (50) of the 0-100 rating scale. The below the mid-point rating (43.87) on familiarity showed that the subjects were not quite familiar with the chosen Mainland China traffic signs. The mean ratings for concreteness, simplicity, meaningfulness, and semantic closeness for all signs were 62.60, 75.81, 69.37, and 68.44, respectively, illustrating that the selected traffic signs were perceived to be moderately concrete, simple and meaningful, and related to their intended meanings. Significant and positive relationships were found amongst the cognitive sign features of familiarity, concreteness, meaningfulness, and semantic closeness. Other than with familiarity, simplicity did not correlate with the other four features. The box plot may be used as a tool for identifying unusual signs for in-depth analysis and for guiding designers to develop new traffic signs at the design stage. The results suggested that cognitive design features are useful for designing more user-friendly traffic signs, which should transmit clear messages about road conditions ahead at the right time to road users. Further research efforts will be given in investigating the effect of sign features on sign comprehension.**

***Index Terms*—cognitive design features, human factors, icon design, traffic signs, usability**

I. Introduction

Traffic signs are used to provide information to regulate, warn, and guide road users in a traffic system [1]. Messages are usually conveyed with the use of symbols, words, or a combination of both. There are some studies addressed to traffic signs on, for instance, sign visibility [2], sign luminance [3], sign conspicuity [4], and sign comprehensibility [5]. The success of effective communication of sign messages to road users may not only relate to the user characteristics but also the signs themselves. Instead of considering icon features that are self-evident (e.g. color and shape) or those that can be identified only in relation to other icons (e.g. distinctiveness), the icon features like familiarity, concreteness, complexity, meaningfulness, and semantic distance are of central concern in icon research [6]. Familiarity is defined in terms of the frequency with which icons had been encountered by subjects. Icons are regarded as concrete if they depict real objects, materials, or people; those that do not depict real objects are considered as abstract. Icons are regarded as complex if they contain a lot of detail or are intricate, and they are simple if they only contain few elements or little detail. Meaningfulness refers to how meaningful the judges perceive icons to be. Semantic distance is a measure of the closeness of the relationship between what is depicted in an icon and the function it is intended to represent. The interrelationships between icon familiarity, concreteness, complexity, meaningfulness, and semantic distance had been examined with two hundred and thirty-nine icons which included computer icons, traffic and public information icons, industrial icons, symbols for household goods [6]. Without consideration of the subject experience of the icons, the results revealed that icon familiarity, concreteness, meaningfulness, and semantic distance were strongly interrelated, whereas icon complexity did not correlate closely with other features. As the frequency of use of an icon would continually reinforce the perceived semantic closeness of the icon [7], the results of interrelationships amongst icon features would be different for naïve and experienced subjects. This experiment aimed to study the cognitive design features of traffic signs with prospective drivers. Mainland China traffic signs were selected and tested in this experiment to reduce any influence of possible daily encounters or prior experience for the subjects. To build more consistent order of response scales amongst the five sign features, the terms ‘complexity’ and ‘semantic distance’ used in [6] were revised as ‘simplicity’ and ‘semantic closeness’, respectively in this study. The collected data were processed and analyzed with appropriate statistical techniques. The results of this experiment should provide useful information and the basis for recommendations for designing more user-friendly traffic signs.

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II. METHOD

A. Subjects

Nineteen male and twenty-two female Hong Kong Chinese undergraduates who have never taken any driving tests, nor possessed any driving license of any sort, voluntarily participated in this experiment. The ages of the subjects were between 18 and 27 years (median = 22.5 years). All subjects had no color deficiency and reported having no previous experience of learning the meanings of the Mainland China traffic signs.

B. Apparatus

The Pesudo-Isochromatic Plates [8] were used to screen for subjects suffering from color deficiency. A Minolta luminance meter (LS-11) was used to measure the luminance levels of testing stimulus materials. A personal computer with 1200MHz microprocessor and 17-inch CRT monitor was used for the experiment. The experimenter used a computer mouse to control stimulus presentation. An adjustable chair was provided for subjects to perform the experiment comfortably. Microsoft PowerPoint was used to prepare self-paced presentation slides for stimulus presentation. A traffic sign features evaluation sheet for subject rating of the sign features was developed. Participants were asked to give subjective ratings between 0 to 100 points for familiarity (0 = very unfamiliar, 100 = very familiar), concreteness (0 = definitely abstract, 100 = definitely concrete), simplicity (0 = very complex, 100 = very simple), meaningfulness (0 = completely meaningless, 100 = completely meaningful), and semantic closeness (0 = very weakly related, 100 = very strongly related) for the signs on the evaluation sheet. The use of a 0 to 100 points scale for rating sign features has two benefits: firstly, respondents prefer to express their feelings on a 0-100 scale [9], and secondly, a higher number of scale points usually results in greater spread of data and makes the data more amenable to various kinds of statistical analyses [10].

C. Stimuli

To minimize the influence of daily encounters or prior experience with traffic signs on the results, instead of using the signs currently used in Hong Kong, 120 traffic signs stipulated in the latest National Standards of the People's Republic of China for Road Traffic Signs and Markings (GB5768-1999 issued in April 1999) were employed. These 120 Mainland China traffic signs were chosen based on two criteria: firstly, their messages are conveyed with symbols only; secondly, they are not used in accompaniment with other signs for transmitting a message. The five Hong Kong traffic signs for pedestrians were used for practice trials prior to actual testing. All the signs were fitted in squares of 7 cm x 7 cm (without boundary) and presented at the centre of the computer screen, subtending angles of 6.65^{o} to subjects' eyes at a viewing distance of 60 cm. For Mainland China traffic signs, verbal labels (in Chinese for describing the meaning of traffic signs) were selected from Yang and Liu [11]. For Hong Kong traffic signs, verbal labels were obtained from the latest Road Users' Code published by Hong Kong Transport Department in 2000. The average luminance of the scenes in the testing stimuli ranged from 25.38 cd/m^2 to 176.5 cd/m^2.

D. Procedure

Subjects were briefed with the rating instructions and meanings of familiarity, concreteness, simplicity, meaningfulness, and semantic closeness at the beginning of the experiment. After practice with the five Hong Kong traffic signs, the 120 testing signs were randomly presented on the screen. For each sign, subjects were asked to give subjective ratings for familiarity, concreteness, simplicity, meaningfulness on the evaluation sheet. After evaluating these four sign features, a verbal label was immediately displayed under the sign and subjects then gave rating for semantic closeness of the sign and the verbal label, after which both of them disappeared. The process repeated until the ratings of all 120 signs were finished. A 1-minute rest was given after every 40 signs were rated. The whole experiment took about one hour to complete.

III. RESULTS

A. Descriptive Statistics

The Mainland China traffic signs examined in this experiment were divided into categories of warning, prohibition, mandatory, guide, tourist, and road works signs. The descriptive statistics of ratings on traffic sign features for signs in the six categories are shown in Table 1. With the exception of familiarity, the mean ratings on the other four sign features for all signs were above the midpoint (50) of the 0-100 rating scale. The below mid-point rating (43.87) on familiarity showed that the subjects were not quite familiar with the chosen Mainland China traffic signs. Table 2 shows the signs with the lowest and highest ratings on familiarity, concreteness, simplicity, meaningfulness, and semantic closeness. The sign M13 (traffic has priority on the main route) was rated as the most unfamiliar with rating of 9.88, while sign P19 (no pedestrians) was rated as the most familiar with rating of 82.93. The high familiarity rating for the sign P19 might be due to the fact that a very similar sign is used in Hong Kong, with only minor difference in the body shape of the man and his walking direction.

The mean ratings for concreteness, simplicity, meaningfulness, and semantic closeness for all signs were 62.60, 75.81, 69.37, and 68.44, respectively, illustrating that the selected traffic signs were perceived to be moderately concrete, simple and meaningful, and related to their intended meanings. The sign M13 (traffic has priority on the main route) was rated as very abstract (18.32) and weakly related to its underlying referent (9.39). The sign P19 (no pedestrians) was perceived to be very concrete (90.80) and strongly related to its intended meaning (95.61). Sign P26 (end of no passing section) was rated as the most complex with rating of 46.83

while sign P2 (vehicles prohibited) was rated as the simplest with rating of 91.66. Sign T4 (camp-site) was identified as the most meaningless with rating of 37.44 whereas sign P13 (non-motor vehicle prohibited) was identified as the most meaningful with rating of 87.29.

Other than the prohibition signs rated at a level 50.22, the mean familiarity ratings for the other five sign types were below the midpoint of the 0-100 rating scale. This may be due to the fact that some similar prohibition signs can be found in Hong Kong (see Table 3). Examples are sign P3 (motor vehicle prohibited; 65.76), sign P19 (no pedestrians; 82.93), sign P27 (temporary or long time parking or stopping prohibited; 53.49), and sign P28 (long time parking or stopping prohibited; 52.73). The road works sign had the lowest mean concreteness (45.20) and meaningfulness (58.29) ratings amongst all sign categories. It comprises of four arrows pointing to the left (). As arrows were generally regarded as abstract objects [12]-[14], it is not surprising that the sign was not perceived as concrete by subjects and could not elicit a meaningful association easily.

Table 1 Descriptive statistics of sign feature ratings in the six categories. The numbers of signs tested in different categories are shown in brackets.

Sign type	Sign features	Mean	SD	CV	Min	Max
Warning (36)	Familiarity	37.13	12.22	32.90	17.17	66.46
	Concreteness	56.16	18.34	32.66	30.68	86.61
	Simplicity	72.95	7.92	10.85	47.93	85.76
	Meaningfulness	66.09	10.51	15.89	38.61	87.22
	Semantic closeness	62.95	17.33	27.52	25.85	87.46
Prohibition (30)	Familiarity	50.22	17.41	34.67	22.80	82.93
	Concreteness	68.79	18.63	27.08	18.90	90.80
	Simplicity	76.93	9.90	12.87	46.83	91.66
	Meaningfulness	71.92	11.15	15.51	40.00	87.29
	Semantic closeness	75.40	19.56	25.94	25.73	95.61
Mandatory (25)	Familiarity	46.98	14.50	30.86	9.88	75.56
	Concreteness	61.22	14.37	23.48	18.32	85.73
	Simplicity	78.85	7.08	8.98	66.02	91.07
	Meaningfulness	71.38	8.80	12.33	45.63	81.88
	Semantic closeness	65.34	17.46	26.72	9.39	86.71
Guide (13)	Familiarity	42.61	16.67	39.11	19.63	78.66
	Concreteness	55.11	22.65	41.09	23.49	85.17
	Simplicity	75.86	7.63	10.06	58.29	85.12
	Meaningfulness	66.05	11.97	18.13	48.88	86.05
	Semantic closeness	62.15	23.40	37.66	10.24	89.37
Tourist (15)	Familiarity	43.14	10.38	24.05	16.59	64.78
	Concreteness	75.64	17.68	23.37	27.20	87.22
	Simplicity	75.25	4.93	6.56	64.88	85.98
	Meaningfulness	72.43	11.76	16.23	37.44	83.85
	Semantic closeness	78.12	20.03	25.63	32.68	95.17
Road works (1)	Familiarity	45.61	NA	NA	NA	NA
	Concreteness	45.20	NA	NA	NA	NA
	Simplicity	76.41	NA	NA	NA	NA
	Meaningfulness	58.29	NA	NA	NA	NA
	Semantic closeness	71.41	NA	NA	NA	NA
Overall (120)	Familiarity	43.87	15.07	34.35	9.88	82.93
	Concreteness	62.60	19.14	30.57	18.32	90.80
	Simplicity	75.81	8.12	10.71	46.83	91.66
	Meaningfulness	69.37	10.88	15.68	37.44	87.29
	Semantic closeness	68.44	19.62	28.67	9.39	95.61

Notes:
SD – standard deviation; CV – coefficient of variation
Min – minimum; Max - maximum
NA - not applicable

To determine if there were any signs with feature ratings very different from other signs, the box plot of ratings for all signs on different sign features were prepared (see Fig. 1). Box plot is a graphical display of data that shows the minimum, first quartile, median, third quartile, maximum, and outliers [15]. The bottom and top lines of the box correspond to the first quartile and the third quartile, respectively, and the horizontal line within represents the median. The vertical lines, whiskers, are drawn from the edges of the box to the largest and smallest values that are outside the box but within 1.5 box lengths. Outlier is a value more than 1.5 box lengths away from the box. No traffic sign was assessed as very different from others in terms of sign concreteness. For sign familiarity, no pedestrians (P19; 82.93) was the only sign marked as outlier above the box, indicating much larger familiarity rating given for this sign than others. With regard to sign simplicity, end of no passing section (P26; 46.83), dangerous mountain (W27; 47.93), and accident-prone (W5; 56.78) were assessed as outliers below the box, suggesting lower simplicity ratings given for these signs. About sign meaningfulness, camp-site (T4; 37.44) and dangerous mountain (W27; 38.61) were signs with extremely small meaningfulness rating. Traffic has priority on the main route (M13; 9.39), pass left side (G12; 10.24), and pass either side (G13; 19.15) had much lower semantic closeness rating. Table 4 shows the signs with suspicious ratings on familiarity, simplicity, meaningfulness, and semantic closeness.

B. Interrelationships

Correlation analysis was used to test for interrelationships amongst the sign features. Green and Salkind [16] specified three assumptions underlying the most widely used indicator of correlation, Pearson correlation coefficient: (i) two sets of data are normally distributed; (ii) the relationship between two sets of data is linear; and (iii) each pair of data is independent from all other pairs. Other than semantic closeness, the ratings on the other four sign features were normally distributed (one-sample Kolmogorov-Smirnov test, $p > 0.05$). Square transformation was then performed on the semantic closeness ratings to make the distribution normal before correlation analysis was carried out (one-sample Kolmogorov-Smirnov test, $p > 0.05$). As noted from Fig. 2, the patterns in the scatterplots approximate straight lines and thus the relationship between any two sign features appears to be linear. By using three standard deviations from the mean as a criterion for identifying extreme cases [17], two data points each in scatterplots for simplicity and concreteness, simplicity and meaningfulness, and simplicity and semantic closeness were considered extreme cases and excluded from the correlation analysis.

After checking the three assumptions and removing the

extreme cases, Pearson correlation analysis was conducted to estimate the relationships amongst the sign features (see Table 5). The linear relationship of concreteness with meaningfulness was noted to possess the highest correlation coefficient (r = 0.731, n = 120, $p < 0.001$). Concreteness also strongly correlated with semantic closeness (r = 0.674, n = 120, $p < 0.001$) and familiarity (r = 0.633, n = 120, $p < 0.001$). Meaningfulness closely associated with familiarity (r = 0.612, n = 120, $p < 0.001$). Semantic closeness correlated with meaningfulness (r = 0.593, n = 120, $p < 0.001$) and familiarity (r = 0.590, n = 120, $p < 0.001$) respectively. With the exception of familiarity (r = 0.543, n = 120, $p < 0.001$), simplicity did not correlate with other features.

Table 2 Signs with lowest and highest ratings on familiarity, concreteness, simplicity, meaningfulness, and semantic closeness. The ratings are shown in brackets.

Sign features	Signs with lowest rating	Signs with highest rating
Familiarity	 M13 – traffic has priority on the main route (9.88)	 P19 - no pedestrians (82.93)
Concreteness	 M13 - traffic has priority on the main route (18.32)	 P19 - no pedestrians (90.80)
Simplicity	 P26 - end of no passing section (46.83)	 P2 - vehicles prohibited (91.66)
Meaningfulness	 T4 - camp-site (37.44)	 P13 – non-motor vehicles prohibited (87.29)
Semantic closeness	 M13 - traffic has priority on the main route (9.39)	 P19 - no pedestrians (95.61)

Table 3 Examples of similar prohibition signs that can be found in Hong Kong. The familiarity ratings are shown in brackets.

Sign	Meaning	Sign	Meaning
	P2 – vehicle prohibited (79.76)		P3 - motor vehicle prohibited (65.76)
	P6 – coach prohibited (52.93)		P7 – lightweight vehicle prohibited (57.17)
	P11 – powered bike prohibited (59.63)		P13 – non-motor vehicle prohibited (80.73)
	P19 - no pedestrians (82.93)		P20 – no left turn (73.20)
	P24 – no U-turn (73.27)		P27 - temporary or long time parking or stopping prohibited (53.49)
	P28 - long time parking or stopping prohibited (52.73)		P29 – no sound signal (58.49)

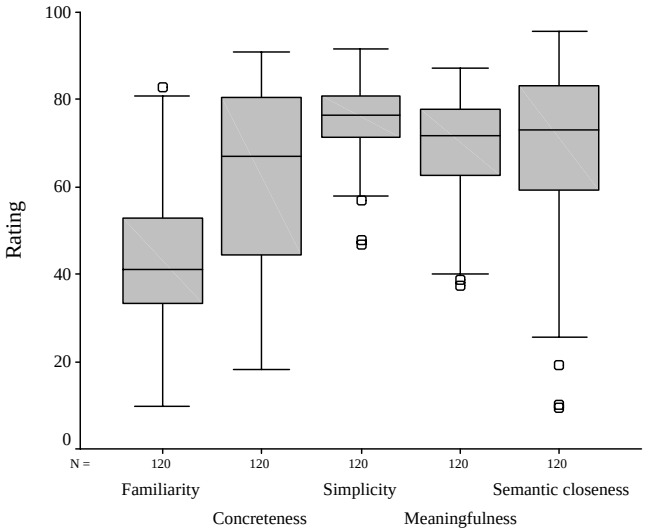

Figure 1 Box plots of ratings on the five sign features for all signs (N = 120). There are one outlier in familiarity, three outliers in simplicity, two outliers in meaningfulness, and three outliers in semantic closeness.

Table 4 Signs with suspicious ratings on familiarity, simplicity, meaningfulness, and semantic closeness. The ratings are shown in brackets.

Sign features	Signs with suspicious rating		
Familiarity	 P19 - no pedestrians (82.93)		
Simplicity	 P26 - end of no passing section (46.83)	 W27 - dangerous mountain (47.93)	 W5 - accident-prone (56.78)
Meaningfulness	 T4 - camp-site (37.44)	 W27 - dangerous mountain (38.61)	
Semantic closeness	 M13 - traffic has priority on the main route (9.39)	 G12 - pass left side (10.24)	 G13 - pass either side (19.15)

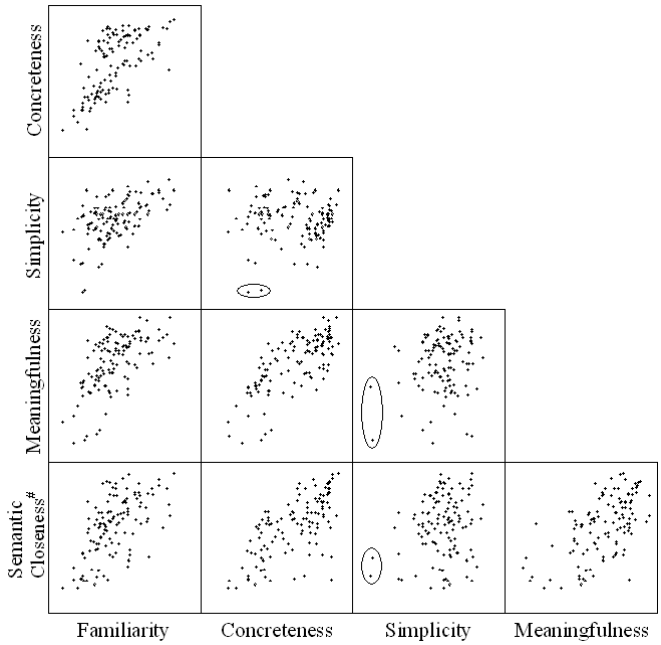

Figure 2 Scatterplots for interrelationships amongst traffic sign features. Extreme cases are enclosed in black and excluded from correlation analyses.

Table 5 Pearson correlation coefficients amongst different traffic sign features

	Familiarity	Concreteness	Simplicity	Meaningfulness
Familiarity	1			
Concreteness	0.633*	1		
Simplicity	0.543*	-0.090	1	
Meaningfulness	0.612*	0.731*	0.109	1
Semantic closeness#	0.590*	0.674*	0.125	0.593*

transformed values was used

* Correlation is significant at the 0.001 level (2-tailed).

IV. Discussion

The traffic sign features studied in this experiment were familiarity, concreteness, simplicity, meaningfulness, and semantic closeness. In general, the selected 120 Mainland China traffic signs were perceived to be moderately unfamiliar, concrete, simple, meaningful, and closeness of sign-function relationship by prospective drivers. The frequency of use of an icon would continually reinforce the perceived semantic closeness of the icon [7]. Hence, experienced drivers would rate the signs with higher ratings on familiarity and semantic closeness as compared with prospective drivers. Additional research is needed for generalization of findings for the experienced drivers.

Earlier research has not determined any method for assessing the signs with feature rating being inconsistent with other signs. The present experiment addressed this issue and found that box plot would be useful for straightforward identification of signs with suspicious feature ratings. The box plot serves as a simple tool for guiding designers to develop traffic signs at the design stage. It is a common practice for traffic sign designers to propose a number of signs for each new referent before conducting analysis and evaluation. The selection of an acceptable sign is usually based on several criteria, with comprehension as the most important one [18]. Where comprehensibility of proposed signs is equal, the results of box plot for subjective ratings on the cognitive sign features would guide the decision of designers.

Significant and positive relationships were revealed amongst the cognitive sign characteristics of familiarity, concreteness, meaningfulness, and semantic closeness in this experiment. Sign meaningfulness was found to be strongly correlated with sign familiarity. It is not surprising as Preece *et al* [13] stated that the meaningfulness of a stimulus depends on its familiarity and associated imagery, which refers to the ability with which the sign can elicit a meaning in one's mind. There was a significant relationship between sign familiarity and semantic closeness, implying that frequency of encounters with a sign would enhance the perceived semantic closeness of the sign. Concrete signs usually illustrate real objects whereas abstract signs do not. It is believed that the frequency with which real objects had been encountered by subjects was higher than that with unreal objects. Thus, sign concreteness associated significantly with sign familiarity. The thinking style of Chinese people tends to be synthetic, concrete, and relying on the periphery of the visible world [19]. Hence, a concrete sign would provide a direct visualization aid in helping Chinese subjects to elicit a meaning and to make links between what is illustrated in the sign and the function it is intended to represent. This may explains why interrelationships existed between concreteness, meaningfulness, and semantic closeness.

Other than with familiarity, simplicity did not correlate significantly with the other four features in the present

experiment. This may be due to the fact that simple signs which contain few elements or little detail were easy to memorize and therefore perceived to be more familiar.

V. Conclusion

This experiment was successful in examining the cognitive design features on traffic signs with prospective drivers. The interrelationships amongst the sign features were assessed. As previous research found that subject experience would affect the perception on feature of semantic closeness [7], an on-going research is needed for generalization of the results for experienced drivers. Box plot identification of outliers in feature ratings was studied. The box plot may be used as a tool for finding out unusual signs for more in-depth analysis and for guiding designers to develop new traffic signs at the design stage. It is believed that consideration of cognitive design features is useful for designing more user-friendly traffic signs, which should transmit clear messages about road conditions ahead at the right time to road users. Further research efforts should be given in investigating the effect of sign features on sign comprehension.

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