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The Guessing of Mine Safety Signs Meaning: Effects of User Factors and Cognitive Sign Features

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This study investigated the effects of user factors and cognitive sign features on the guessability of mine safety signs. Sixty naïve participants guessed the meanings and rated the cognitive sign features of 42 Mainland Chinese mine safety signs. The results showed that some user factors were significant predictors of guessing performance, while some were not. As expected, guessability scores varied significantly with the cognitive sign features of familiarity, concreteness, simplicity, meaningfulness and semantic closeness. The findings emphasize the need to create awareness of the importance of mine safety and promote understanding of mine safety sign meanings amongst people in their work environments. To design more user-friendly mine safety signs, industrial designers should develop and evaluate signs with consideration of the significant user factors and the 5 sign features tested here.

mine safety signs   guessability   user factors   cognitive sign features

1. INTRODUCTION

In Mainland China, coalmine accidents constitute the highest percentage of industrial accidents, and the total death toll from coalmine accidents far surpasses the other main coal-producing countries like the USA, the Russian Federation, Poland, India and South Africa [1, 2]. Two thousand, four hundred and thirty-three people died in mine accidents in China in 2010; that is an average of 6.67 miners killed each day of a year [3]. As a ratio to the amount of coal produced, 0.749 miners lost their lives for the production of one million tons of coal [4]. A previous study indicated that coal mining safety could be increased through a systematic establishment of limits for methane and coal dust [5]. However, one of the major reasons for the high fatality rates in the Mainland China is ignorance of mine safety, which leads to poor safety training for miners, outdated safety equipment and an obsolete safety management system [6, 7].

In the mine safety management system, signage is a system component used for delivering prohibition, mandatory, warning and guidance messages to mining workers to promote appropriate and responsible behaviour in mine areas [8]. Most Chinese miners are poorly educated and it is likely that they have relatively poor written and verbal language skills with consequent inadequate knowledge of the language used in warning notices and verbal instructions. Using mine safety symbols seems to be a potentially effective safety measure that can be implemented quickly to try to reduce the occurrence of mining accidents and fatalities. Apart from Yu, Chan and Salvendy's study on the perception of implied hazard of signal words and surround shapes recommended for Chinese general safety signs [9], not much work has been published

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specifically on safety for mines in Mainland China. Standard No. GB 14161-1993 recommended 55 mine safety signs conveying prohibition, warning, mandatory and guidance messages for mine working areas to reduce accidents and injuries [10]. Workers who have never received any safety training on the use of mine safety signs must guess the meaning of each sign at first encounter.

In relation to usability-based approaches to product and service design, Jordan identified an important usability component, guessability, which is a measure of the cost (e.g., in terms of time on task or errors made) to the user of a product when performing a task for the first time; the higher the guessability, the lower the cost [11]. To provide a safe work environment for coal mine workers, the design of mine safety signs that are easy to guess is important. Therefore, it is necessary for ergonomists to investigate the effects of factors affecting the guessability of such safety signs and to design and select safety signs with a high level of usability.

The purpose of this study was to evaluate the guessability of existing mine safety signs in Mainland China by considering user factors and sign design features for a group of naïve users. The "gender" factor and seven other user factors that were thought to be related to experience with safety signs in daily life were selected for examination here, namely, "work experience in a laboratory or on a construction site", "laboratory or construction site visit experience", "awareness of safety signs in daily life", "injury experience due to ignorance of safety signs", "family member working at laboratory, construction or mine site", "Mainland China visit experience" and "driving experience". Except for the factor of "gender", the other seven user factors were expected to have a positive influence on sign guessing performance. In a study on traffic sign comprehension, it was found that male drivers had significantly better comprehension of signs than females, a result probably confounded with the effect of education level [12]. By controlling for the education factor in this study, it was expected that males and females would have similar guessing performance levels.

Successful and effective communication using safety sign messages not only relates to the characteristics of the users but also to the design of the signs. According to McDougall, Curry and de Bruijn, the cognitive features of central concern in sign research are familiarity, concreteness, complexity, meaningfulness and semantic distance [13]. Familiarity is the frequency with which signs have been encountered in the past. A concrete sign has some obvious connection with the real world, while an abstract one consists mainly of shapes, arrows and lines. Signs are regarded as complex if they contain a lot of detail or are intricate, and simple if they contain few elements or little detail. Meaningfulness refers, rather obviously, to how meaningful the sign is perceived to be. Semantic distance is the closeness of the relationship between what is depicted on a sign and what it is intended to represent. In this study, it was expected that users would guess signs better if they were familiar. Also, because concrete signs provide a direct visualization aid in helping participants to elicit the meaning, concrete signs were expected to lead to higher guessability scores than abstract ones. Extraneous decorative parts on signs may confound understanding of the signs [14], so it was hypothesized here that simple signs would be easier to guess than complex ones. The meaningfulness of a stimulus depends on its associated imagery and refers to the ease with which it can elicit a meaning in one's mind [15]. Hence, better guessing ability was expected for the more meaningful signs. For semantic closeness, signs that are perceived to be associated with a concept were expected to lead to higher guessability scores. The aim of this study was to investigate the effects of user factors and sign design features on the guessability of mine safety signs. It is hoped that the results will provide useful information for designing more user-friendly mine safety signs to convey safety messages in mine working areas, so as to reduce the occurrence of mining accidents and fatalities.

2. METHOD

To conduct the study, a self-administered on-screen questionnaire was developed to capture demographics, colour vision deficiencies, user factors, sign guessing scores and ratings on sign features of the participants.

2.1. Participants

Thirty male and 30 female Hong Kong Chinese, all with tertiary-level education, participated voluntarily in this study. Their age ranged from 20 to 35 years (*Mdn* = 23). None of them had colour vision deficiencies and none had any previous experience of working in a mine, going on a mine visit or learning the meanings of Mainland Chinese mine safety signs. Hong Kong Chinese, rather than mine workers, were used for testing in this study to avoid prior experience with mine safety signs. The results would then give some valid indication of the guessability of mine safety signs when presented to relatively naïve observers.

2.2. Apparatus

A colour vision test [16] was used to screen out candidates suffering from red–green colour deficiency. A personal portable computer with a 1.60-GHz microprocessor and a 10.2″ LCD monitor was used for the study. The computer language Java was used to prepare the on-screen questionnaire.

2.3. Mine Safety Signs

Forty-two of 55 Mainland China mine safety signs in the categories of prohibition, warning, mandatory and guide signs [10] were used for the tests (Table 1). They were chosen because their messages were conveyed with symbols only and the signs were not used in conjunction with other signs to transmit a message. Each sign was fitted into a 7 × 7 cm square with no boundary and presented at the centre of the computer screen for testing.

2.4. Questionnaire

The questionnaire was prepared in Chinese. Chinese was used because it was the most effective means of communication with the participants. Each participant read the objectives and instructions for the tests on the screen at the beginning of the study. The first part of the questionnaire asked about demographic information: education background, age and gender. The second part was a colour vision test. The third part was designed to capture data concerning the user factors. Participants were asked to answer seven closed-ended questions about "work experience in a laboratory or on a construction site"; "laboratory or construction site visit experience in the past 12 months"; "awareness of safety signs in daily life"; "injury experience due to ignorance of safety signs in the past 12 months"; "family member working at laboratory, construction or mine site"; "Mainland China visit experience in past 12 months"; and "driving experience". The seven questions required the participants to click *yes* or *no* boxes only. The fourth part was the guessing test for the mine safety signs using the multiple-choice method. Five Hong Kong safety signs were provided for practice prior to the random testing of the 42 signs. In each sign presentation, five verbal labels were presented but only one label was correct, there were 1–2 partially correct answers and the rest were incorrect. Participants selected the most appropriate verbal label to describe the meaning of the test sign. This process was repeated until the guessing for all signs was finished. No feedback was given to participants during the test. The fifth part of the questionnaire involved evaluating sign features. Participants were briefed about the rating instructions and the meanings of the five cognitive features (Table 2). The testing sequence of the 42 test signs was random. For each presentation, the sign was presented at the centre of the computer screen, the verbal label was placed under the sign, and the rating scales were shown under the label. Participants were asked to give subjective ratings of 0–100 for the features of familiarity (0—*very unfamiliar*, 100—*very familiar*), concreteness (0—*definitely abstract*, 100—*definitely concrete*), simplicity (0—*very complex*, 100—

TABLE 1. Mainland China Mine Safety Signs and Verbal Labels Used in This Study

Reference No.	Sign	Verbal Label	Reference No.	Sign	Verbal Label
P1		禁帶煙火 Do not light fires	P2		嚴禁酒後入井 Do not enter mine after drinking alcohol
P3		禁止明火作業 No open flames	P4		禁止啟動 Do not use the starter
P5		禁止合閘 Do not turn the switch on	P6		禁止扒乘礦車 Do not ride on the mine wagon
P7		禁止乘輸送帶 Do not ride on the conveyor belt	P8		禁止車間乘人 No passenger on the mine wagons
P9		禁止乘人登鈎 No passenger on mine wagon hooks	P10		禁止跨輸送帶 Do not cross the conveyor belt
P11		禁止攀牽線纜 Do not use the cable for climbing	P12		禁止料罐乘人 Do not ride in hoist buckets
P13		禁止入內 No entry	P14		禁止通行 No thoroughfare
P15		禁止停車 Wagons must not stop	P16		禁止駛入 No vehicles

Reference No.	Sign	Verbal Label	Reference No.	Sign	Verbal Label
W1		注意安全 Caution, danger	W2		當心冒頂 Caution, roof fall
W3		當心火災 Caution, fire	W4		當心有害氣體中毒 Caution, noxious gas poisoning
W5		當心爆炸 Caution, explosion	W6		當心觸電 Danger! Electric shock
W7		當心墜落 Caution, dangerous drop	W8		當心墜入溜井 Caution, open drain or well
W9		當心片幫滑坡 Caution, landslide	W10		當心礦車行駛 Caution, mine wagon
W11		當心列車通過 Caution, train	W12		當心交叉道口 Caution, cross junction
W13		當心彎道 Caution, bend	M1		必須戴礦工帽 Must wear mining cap
M2		必須攜帶礦燈 Must bring mining lamp	M3		必須帶自救器 Must bring self-rescuer
M4		必須穿戴絕緣保護用品 Must wear insulated protective products	M5		必須繫安全帶 Must fasten safety belt

M6		必須戴防塵口罩 Must wear dustproof mask	M7		必須橋上通過 Must use the bridge
M8		走人行道 Walk on the pedestrian area	M9		鳴笛 Horn must be used
G1		安全出口 Emergency exit	G2		電話 Telephone
G3		躲避硐 Refuge	G4		急救站 First aid station

Notes. P—prohibition signs, W—warning signs, M—mandatory signs, G—guide signs. The English labels are translated from the Chinese labels in Standard No. GB14161-1993 [10].

TABLE 2. Rating Instructions and Meaning of Sign Features

Cognitive Sign Feature		**Description**		
Familiarity	definition	Familiarity is defined in terms of the frequency with which mine safety signs have been encountered.		
	evaluation criterion	*very unfamiliar* 0	←→	*very familiar* 100
	example			
Concreteness	definition	Mine safety signs are to be regarded as concrete if they deficit real objects, materials, or people; those that do not are to be regarded as abstract.		
	evaluation criterion	*definitely abstract* 0	←→	*definitely concrete* 100
	example			
Simplicity	definition	Mine safety signs are regarded as complex if they contain a lot of details or are intricate, and as simple if they contain few elements or little detail.		
	evaluation criterion	*very complex* 0	←→	*very simple* 100
	example			
Meaningfulness	definition	Meaningfulness refers to how meaningful you perceive mine safety signs to be.		
	evaluation criterion	*completely meaningless* 0	←→	*completely meaningful* 100
	example			
Semantic Closeness	definition	Semantic closeness is a measure of the closeness of the relationship between what is depicted in a mine safety sign and the function it is intended to represent.		
	evaluation criterion	*very weakly related* 0	←→	*very strongly related* 100
	example	 health service		 flower

very simple), meaningfulness (0—*completely meaningless*, 100—*completely meaningful*) and semantic closeness (0—*very weakly related*, 100—*very strongly related*). Instead of entering the rating into the box provided, participants moved the marker from the midpoint (50) of the 0–100 scale to their perceived rating level for each feature. The process was repeated until all signs were rated. The questionnaire took ~2 h for each participant to complete.

3. RESULTS

In this study, guessability score refers to the accuracy level for guessing the meaning of a sign, while guessing performance denotes the overall performance level of a participant in the guessing task.

3.1. Guessability Score

In the guessing test, a score of 2 was given for a correct response, i.e., the one that gave the intended precise description of the meaning of the sign. One mark was given for a partially accurate response which gave only part of the meaning. A response was considered incorrect and a zero mark was given if the selected item did not give any correct or partly correct description of the meaning of the sign. Table 3 shows the descriptive statistics for the guessability scores for the signs in the four categories. The mean and standard deviation of scores for all 42 signs were 59.98 and 21.87%, respectively. The mean guessability scores for the different categories of signs were all over 50%. The warning signs had the highest coefficient of variation and highest spread in guessability. For individual signs, the "caution, noxious gas poisoning" (W4) sign had the minimum, and lowest possible, guessability score (0%), because no participants interpreted it correctly. The participants guessed it to be "caution, crosswind", "caution, air current", "caution, gaseous detonation" or "caution, gas liberation". The sign with the maximum, and highest possible, guessability score (100%) was "emergency exit" (G1).

TABLE 3. Descriptive Statistics of Guessability Score for Signs in 4 Categories (%)

Sign Type	*M*	*SD*	CV	Min	Max
Prohibition (16)	53.07	14.77	27.83	26.67	78.33
Warning (13)	59.68	24.47	41.01	0.00	96.67
Mandatory (9)	62.31	24.86	39.89	28.33	95.83
Guide (4)	83.33	20.06	24.07	54.17	100
Overall (42)	59.98	21.87	36.46	0.00	100

Notes. CV—coefficient of variation.

The International Organization for Standardization (ISO) and the American National Standard Institute (ANSI) recommend that symbols must reach a criterion of at least 67 or 85% correct, respectively, in a comprehension test to be considered acceptable [17, 18]. The results here showed that eight mine safety signs reached both the ISO and ANSI criteria, namely, "emergency exit" (G1; 100%), "caution, explosion" (W5; 96.67%), "must use the bridge" (M7; 95.83%), "telephone" (G2; 90%), "first aid station" (G4; 89.17%), "caution, dangerous drop" (W7; 89.17%), "must fasten safety belt" (M5; 86.67%) and "must wear dustproof mask" (M6; 85%). Another six mine safety signs achieved the lower criteria of the ISO only, namely, "danger! Electric shock" (W6; 83.33%); "do not ride on the conveyor belt" (P7; 78.33%); "do not cross the conveyor belt" (P10; 76.67%); "horn must be used" (M9; 74.17%); "caution, roof fall" (W2; 70%) and "caution, open drain or well" (W8; 69.17%).

To determine if there were any signs with variability of guessability score very different from other signs, a box plot of coefficients of variation on guessability score for all signs was prepared (Figure 1). "Must wear insulated protective products" (M4; 160.38%) was assessed as an outlier above the box, indicating that the dispersion of guessing score on this sign was much larger than for other signs. An outlier has a value of over 1.5 box lengths (difference between 75th and 25th percentiles) away from the box and the outlier is flagged with a small circle in the box plot [19].

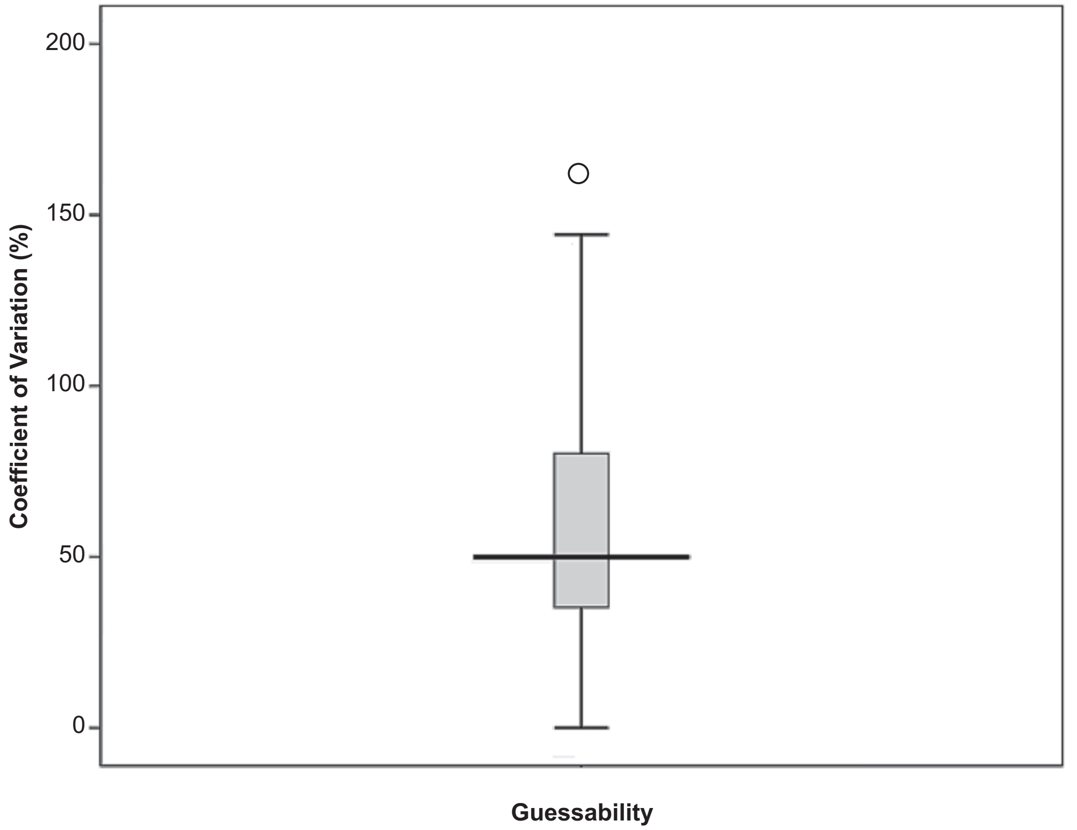

Figure 1. Box plot of coefficients of variation on guessability score for all signs. *Notes.* One outlier ("must wear insulated protective products") is flagged with a small circle.

3.2. User Factors and Guessing Performance

Table 4 shows the number and percentage of participants' responses to each user factor, and the guessing performance of the participants in each response category. The average guessing performance for individual participants was 48.29% (47.62–79.76%, *SD* 8.54%). Guessing performance for the factors of "laboratory or construction site visit experience", "awareness of safety signs in daily life" and "gender", yielded results that were adequately normal but results for the other user factors were not adequately normal (Shapiro–Wilk's test, $p < .05$). Apart from the result for the factors of "working" and "visiting experience at laboratory or construction site", variances for all the other factors were equal (Levene's test, $p > .05$). Therefore, the effects of "gender" and "awareness of safety signs" on guessing performance were analysed with analysis of variance (ANOVA), whereas the effects of the remaining six user factors on guessing performance were examined with the Kruskal–Wallis test. The results of the Kruskal–Wallis test showed significant main effects for "working at a laboratory or on a construction site" ($\chi^2 = 10.25$, $df = 1$, $p < .01$), "laboratory or construction site visit experience in past 12 months" ($\chi^2 = 5.47$, $df = 1$, $p < .05$), "injury experience due to the ignorance of safety signs in past 12 months" ($\chi^2 = 14.58$, $df = 1$, $p < .001$) and "driving experience" ($\chi^2 = 14.11$, $df = 1$, $p < .001$). Participants who "worked at a laboratory or on a construction site" were better at guessing the meanings of mine safety signs (65.66%) than those who did not (57.35%). Participants who had the "experience of visiting laboratory or construction site" had significantly better guessing performance (62.50%) than those who did not (56.69%). Participants who had "injury experience due to the ignorance of safety signs" performed better (68.45%) than those without injury experience (57.40%). And participants who had "driving experience" performed better in sign guessing

TABLE 4. A Summary of Responses for User Factors and Mean Guessing Performance for Different Groups of Participants

User Factor	Response	No. (%)	Guessing Performance (%)	
			M	*SD*
Work experience at a laboratory or construction site	yes	19 (32)	65.66	9.48
	no	41 (68)	57.35	6.68
Laboratory or construction site visit experience in past 12 months	yes	34 (57)	62.50	9.55
	no	26 (43)	56.69	5.64
Awareness of safety signs in daily life	yes	41 (68)	62.17	8.68
	no	19 (32)	55.26	6.09
Injury experience due to ignorance of safety signs in past 12 months	yes	14 (23)	68.45	9.28
	no	46 (77)	57.40	6.45
Family member working at a laboratory, construction or mine site	yes	9 (15)	62.70	11.20
	no	51 (85)	59.50	8.02
Mainland China visit experience in past 12 months	yes	24 (40)	59.33	9.62
	no	36 (60)	60.42	7.85
Driving experience	yes	20 (33)	66.07	8.56
	no	40 (67)	56.93	6.78
Gender	male	30 (50)	60.04	8.87
	female	30 (50)	59.92	8.35

TABLE 5. Descriptive Statistics of Sign Feature Ratings in 4 Categories

Sign Type	Sign Feature	*M*	*SD*	CV (%)	Min	Max
Prohibition (16)	familiarity	34.46	21.76	63.16	15.52	87.42
	concreteness	52.13	16.56	31.76	13.15	68.35
	simplicity	59.72	11.49	19.24	43.95	86.28
	meaningfulness	57.32	14.62	25.51	17.35	73.60
	semantic closeness	58.76	18.27	31.09	16.20	78.93
Warning (13)	familiarity	50.58	25.28	49.97	12.05	78.80
	concreteness	51.90	18.50	35.65	17.82	80.33
	simplicity	63.37	17.29	27.29	44.15	86.43
	meaningfulness	52.73	18.39	34.87	15.73	76.95
	semantic closeness	54.75	19.84	36.23	16.75	79.57
Mandatory (9)	familiarity	44.76	24.49	54.72	11.63	81.45
	concreteness	51.23	21.94	42.83	16.58	78.55
	simplicity	65.67	10.15	15.46	49.17	78.70
	meaningfulness	55.64	19.24	34.59	21.85	76.67
	semantic closeness	56.24	23.43	41.67	14.97	81.75
Guide (4)	familiarity	73.22	30.32	41.41	27.90	91.43
	concreteness	78.73	13.85	17.59	58.60	90.18
	simplicity	81.55	9.28	11.38	68.75	90.65
	meaningfulness	83.24	10.23	12.28	68.32	90.50
	semantic closeness	81.67	14.54	17.81	60.15	91.33
Overall (42)	familiarity	45.35	25.99	57.31	11.63	91.43
	concreteness	54.40	19.30	35.47	13.15	90.18
	simplicity	64.21	14.15	22.03	43.95	90.65
	meaningfulness	58.01	18.15	31.29	15.73	90.50
	semantic closeness	59.16	20.43	34.53	14.97	91.33

Notes. CV—coefficient of variation.

(66.07%) than those who did not (56.93%). The effects of "family member working at laboratory, construction or mine site" and "Mainland China visit experience in past 12 months" were nonsignificant ($p > .05$). The results of ANOVA showed a significant main effect of awareness of safety signs; $F(1, 59) = 9.75$, $p < .005$. Participants who were "aware of safety signs in daily life" performed better in sign guessing (62.17%) than those who did not (55.26%). "Gender" was nonsignificant ($p > .05$).

3.3. Cognitive Sign Features

3.3.1. Descriptive statistics

Table 5 shows the descriptive statistics for the ratings of cognitive sign features for the four categories of signs. The rating for familiarity (46.48) was below the midpoint (50) of the 0–100 rating scale, showing that the participants were not familiar with the Mainland China mine safety signs tested here. The mean ratings for the other four sign features were above the midpoint, indicating that the selected mine safety signs were perceived to be moderately concrete (54.40), simple (64.21), meaningful (58.01) and related to their intended meanings (semantic closeness, 59.16). The prohibition signs had the lowest mean familiarity (34.46) and simplicity (59.72) ratings amongst all sign categories, while the mandatory signs had the lowest mean concreteness (51.23) and the warning signs had the lowest mean meaningfulness (52.73) and semantic closeness (54.75) ratings amongst all categories.

Table 6 shows the signs with the lowest and highest ratings for the five cognitive sign features. Sign M3 had the lowest familiarity rating (11.63) whereas sign G2 had the highest (91.43), probably because this telephone sign is very common and a very similar sign is used in Hong Kong and many other countries. To determine whether there were any signs with rating features very different to other signs, box plots of coefficients of variation for ratings on individual sign features for all signs were plotted (Figure 2). The results showed that subjective rating on all five sign features differed significantly from sign to sign. Sign M2 was the sign with highest coefficients of variation in concreteness rating, while sign W4 had the highest coefficient of variation on meaningfulness rating.

TABLE 6. Signs With Lowest and Highest Ratings on Familiarity, Concreteness, Simplicity, Meaningfulness and Semantic Closeness

Sign Features		Signs With Lowest Ratings		Signs With Highest Ratings
Familiarity		M3—must bring self-rescuer (11.63)		G2—telephone (91.43)
Concreteness		P15—wagons do not stop (13.15)		G2—telephone (90.18)
Simplicity		P15—wagons do not stop (43.95)		G2—telephone (90.65)
Meaningfulness		W4—caution, noxious gas poisoning (15.73)		G2—telephone (90.5)
Semantic closeness		M3—must bring self-rescuer (14.97)		G2—telephone (91.33)

Notes. P—prohibition signs, W—warning signs, M—mandatory signs, G—guide signs.

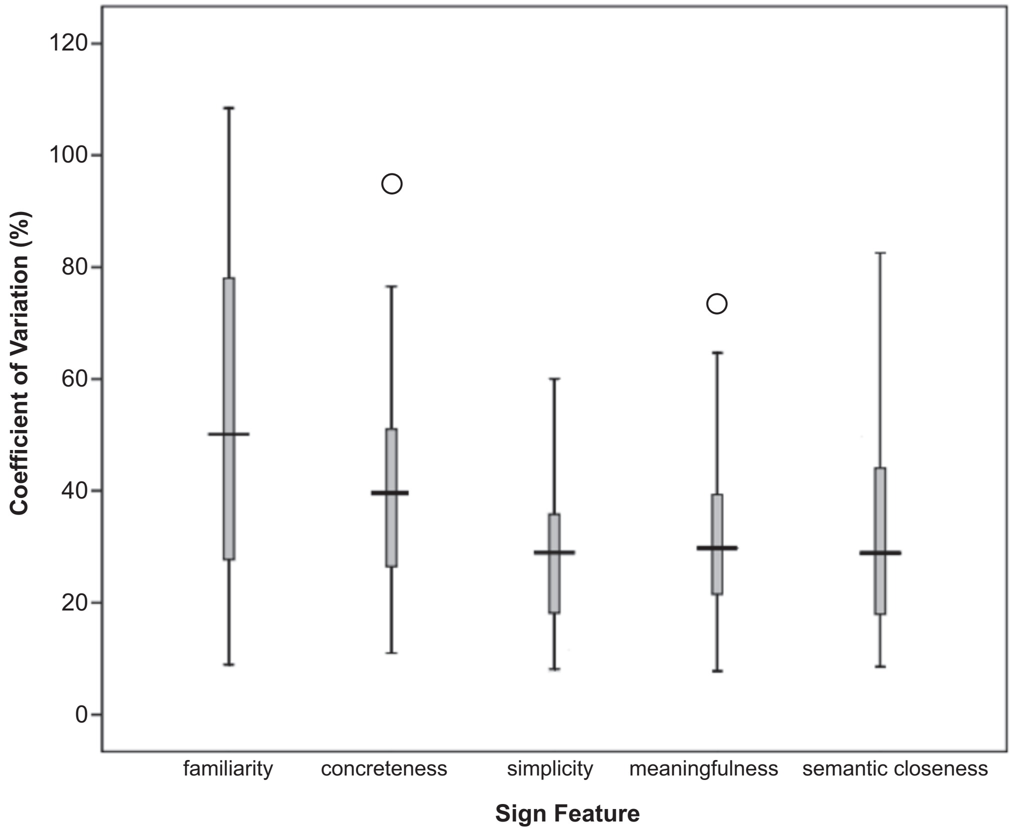

Figure 2. Box plots of coefficients of variation for ratings on 5 sign features for all signs (n = 42).
Notes. There is one outlier in concreteness and one outlier in meaningfulness.

TABLE 7. Pearson Correlation Coefficients Amongst Mine Safety Sign Features and Guessability Score

Sign Feature	Familiarity	Concreteness	Simplicity	Meaningfulness	Semantic Closeness
Concreteness	.707**	1			
Simplicity	.826**	.651**	1		
Meaningfulness	.686**	.923**	.712**	1	
Semantic closeness	.717**	.947**	.704**	.942**	1
Guessability score	.557**	.568**	.359*	.593**	.555**

Notes. **significant at .01 (2-tailed), *significant at .05 (2-tailed).

3.3.2. Interrelationships amongst cognitive sign features

Here, the interrelationships among the cognitive design features of the mine safety signs were investigated. The ratings for all sign features were normally distributed (Kolmogorov–Smirnov, $p > .05$). Therefore, Pearson correlation analysis was conducted on the ratings (Table 7) and the results showed that there were significant interrelationships among the sign features. The highest correlation was for semantic closeness with concreteness ($r = .947$, $n = 42$, $p < .01$).

3.4 Interrelationships Between Cognitive Sign Features and Guessability

Correlation analysis was conducted to test the hypotheses that guessing scores would be higher for familiar signs, concrete signs, simple signs, meaningful signs, and for signs with higher semantic closeness ratings. Pearson correlation analysis showed that all five sign features were positively and significantly correlated with guessability score (Table 7). Meaningfulness was correlated most highly with guessability score ($r = .593$, $n = 42$, $p < .01$), while simplicity correlated with guessability score at the lowest level of significance ($r = .359$, $n = 42$, $p < .05$).

4. DISCUSSION

The tests here showed that guessing scores differed greatly from sign to sign. According to the 67% correctness criterion [17], only 14 of the 42 mine safety signs were acceptable for effectively communicating relevant information in mine working areas. If the more demanding criterion of 85% [18] was considered, only eight signs were found to be acceptable. Although the multiple-choice methodology of testing here differs from the open-ended questions approach adopted in the ISO and ANSI standards, the relatively low guessability scores in general showed that the mine safety signs did not transmit the intended messages to participants and the currently used mine safety signs should be redesigned as soon as possible with careful consideration of user factors and cognitive sign features. The guessability tests involved naïve users with regard to the signs so the result is particularly relevant to those who had not learned the signs before, and this may be a common circumstance in some developing countries, where many mine workers do not receive any or sufficient training about safety issues prior to starting work. This study was conducted with young voluntary participants, most of whom had tertiary-level education. It has been shown in a traffic sign study that participants with university education or above had significantly better comprehension of traffic signs than those without university education [20]. Other studies on icon and pictogram comprehension also showed that low-literate participants had relatively poorer comprehension than high-literate ones [21, 22]. It seems very likely that the guessability scores for the miners in Mainland China, most of whom are poorly educated [23], would be lower than in this study; if so, there is cause for alarm. It is suggested that there should be an effective education program to promote the intended messages of such signs for the miners.

Of the eight user factors in this study, "family member working at laboratory, construction, or mine site", "Mainland China visit experience" and "gender" were not significant predictors of guessing performance. The hypothesis that males would show the same guessing performance level as females was thus upheld. This may be due to the fact that both the male and female participants had the same level of education. Cultural background has been noted as an important determinant factor influencing sign comprehension performance [24, 25]. However, in this study, the Hong Kong participants with Mainland China visit experience did not guess signs better. It was probably that the messages conveyed by the test signs were not related to the general cultural issues in Mainland China.

The "work experience at a laboratory or on a construction site", "laboratory or construction site visit experience" and "driving experience" had positive effects on guessing performance. This might be because participants with such experience were required to pay attention to the safety signs around and thus could more easily interpret the signs in this guessing study. In particular, participants with driving experience must necessarily be familiar with the sign system as they have learned to understand and obey the road users' code and meanings of traffic signs. The mine safety signs here, like general industrial safety signs and traffic signs, are made of three components: image/text, border and background. The border shape identifies the type of information that the sign is transmitting. For example, a triangular sign means warning, a circular sign is mandatory and a quadrilateral sign depicts guide information. This may explain why participants in this group performed better in guessing the intended meanings of mine safety signs, and suggest that provision of training on shape coding principle may be useful in sign interpretation.

The results also showed that injury experience due to ignorance of safety signs had a positive effect on guessing performance, suggesting that bad experience enhances individual knowledge about safety signs. Certainly, ergonomists do not want workers to understand the intended messages of safety signs after being involved in an accident. Also, participants who paid attention to safety signs in daily life were able to guess the underlying messages of mine safety signs better. Overall, the results suggest that there is a need to enhance miners' risk perception and to increase awareness of the importance of mine safety signs through training and education programs.

Guessability scores varied with the five sign features in this study; they were high for familiar signs and low for unfamiliar ones. Recent studies on traffic sign comprehension also found that signs that were only encountered infrequently were more likely to be misunderstood than frequently seen signs [26, 27]. However, what is familiar to one person may not be familiar to another. Ergonomists often have difficulties in envisaging user situations and unarticulated wants and requirements, so decisions about sign design that involve assumptions about familiarity should be made together with prospective users. Concrete signs had higher guessability scores than abstract ones. Where signs were abstract, access to meaning seemed much more difficult. Thus, ergonomists need to pay attention to the pictorial design of mine safety signs, which should have an obvious and direct connection with our daily life. Also, simple signs had higher guessability scores than complex ones, indicating that extraneous decorative parts would confound understanding. Marcus recommended that good icon design should be simple and clear [28]; Dewar showed that simple symbols were better than complicated ones especially when perceived at a distance [29]. Blijlevens, Creusen and Schoormans also showed that users perceived simplicity as an important appearance attribute of durable products [30]. If only the most distinctive and characteristic features of an icon are retained, it may be possible to create a simpler and more easily interpreted icon [31]. For sign meaningfulness, the guessability scores were high for meaningful signs and low for meaningless ones. Regarding semantic closeness, the signs should also be a direct visualization aid in helping people elicit a meaning and then making links between what the sign illustrates and the function it is intended to represent. Overall, as expected, the guessability of mine safety signs was better when the signs were familiar, concrete, simple, meaningful, or associated with the underlying concepts.

This study has served to indicate some effects of user factors and sign design features on the guessability of mine safety signs. However, there were limitations to the experimental design used in this study. For example, a multiple-choice test method was used to gather information on sign guessing scores. Wolff and Wogalter found that compared to an open-ended test, a multiple-choice test lacked the ecological validity in reflecting the real-world task of symbol comprehension [32]. However, the multiple-choice assessment method was chosen here because of its efficiency as a testing method, the reduced need for cross-checking results, its high inter-rater reliability and good coverage of content in tests [33, 34]. This might explain why there are still many multiple-choice sign testing studies [25, 35, 36]. In addition, the participants of this study were younger Chinese people, the findings obtained may not be generalizable to non-Chinese people. Previous research found that the hazard perception of safety words and colours, and the interpretation of safety symbols for industry workers varied significantly in different countries [37, 38]. Further research is thus needed with people of different ethnicities to generalize the results.

5. CONCLUSION

This study demonstrated that user characteristics and sign features are important for signs to effectively communicate mine safety messages to users. The findings emphasize the need to create usable mine safety signs, and provide useful information for the design of more assessable and effective mine safety signs. It is recommended that the mine safety signs should be developed in accordance to the principles of existing signage system and provision of training on shape coding principle may help guessing of sign meanings. There is also a need to enhance miners' risk perception and increase awareness of the importance of mine safety messages by means of sign design and training. In addition, the cognitive sign features of familiarity, concreteness, simplicity, meaningfulness and semantic closeness should be considered in the design of mine safety signs. The pictorial design of a sign should have obvious and direct connection with our daily life, and the most distinctive and characteristic features of a sign need to be retained. Moreover, the signs should be designed to be perceived as meaningful and associated with the intended messages.

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