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Safety sign comprehension by students, adult workers and disabled persons with cerebral palsy

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A B S T R A C T

This research carried out comprehension testing on a set of symbol-based safety signs using three diverse groups of participants that included adult workers, college students and persons afflicted with cerebral palsy. Few studies have examined "differently abled" populations with respect to safety signs. Open comprehension testing of a set of 17 symbol-based safety signs was carried out using ISO (International Organization for Standardization) 9186 criteria. The intended message for each safety sign was conveyed via two components, a graphical symbol and a surrounding shape–color background. Results showed that most of the signs were not well understood. In some cases, participants were able to correctly understand the meaning of the symbol, but failed to understand the meaning of the shape–color code or vice versa. In general, the adult workers and college students achieved higher comprehension scores than individuals with cerebral palsy. Despite the lower scores obtained by the cerebral palsy group, the pattern of comprehension levels for the "good" and "bad" signs were similar across the three groups. Other findings included statistically significant associations between comprehension and the individual/experience variables (e.g., age, gender, and have a driver's license). Issues associated with categorizing participant responses, including the use of criteria for separately evaluating the meaning of the symbols and color–shape codes, are discussed.

1. Introduction

An ultimate purpose of safety signs is to promote safety-appropriate behavior. However, many safety signs in current use are poorly designed. They lack features and characteristics demonstrated to aid effectiveness and relatively few signs are subjected to systematic evaluation by a representative sample of target users before they are placed into service (Wogalter, 2006).

Symbols are a frequently-used component of safety signs and warnings, with and without accompanying text or other cues, such as background shape and color. Symbols have the potential to benefit warnings and signs in various ways. In general, symbols have an alerting value, which is important especially in cluttered environments. Several studies have found that warnings with symbols are more noticeable than warnings without symbols (e.g., Bzostek and Wogalter, 1999; Kalsher et al., 1996; Laughery et al., 1993). Symbols also aim to foster compliance (e.g., Friedmann, 1988; Jaynes and Boles, 1990; Wogalter et al., 1993). However, some studies have found no effect of symbols on compliance (e.g., Otsubo, 1988). Symbols are also being used as a means of trying to accomplish risk communication given the diversity of languages used in the global marketplace. The growing reliance on symbols to communicate safety information is also an attempt to reach an increasingly broad range of product users (Young and Wogalter, 1990). However, group differences in symbol comprehension have been reported: low comprehension has been found in older adults (e.g., Hancock et al., 1999, 2004; Lesch et al., 2011; Sojourner and Wogalter, 1998); low educational level and lack of symbol familiarity are associated with lower symbol comprehension (Mishra and Gupta, 1983), and other cultural differences have been also noted (Choong and Salvendy, 1998; Smith-Jackson and Essuman-Johnson, 2002; Smith-Jackson and Wogalter, 2000).

Given their importance in safety, symbols should be designed in order to be correctly understood. While lack of understanding should be reduced, it is particularly serious in case of critical

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confusions. Critical confusions are misunderstandings opposite to the intended meaning that might lead to injury. Additionally, symbol design should consider individual and group differences so that they serve inclusively when possible. Despite these seemingly necessary communication goals for symbols, most symbols in use on products and environments have not been tested to determine whether the intended target users understand them. Moreover the few studies that have tested symbols have generally not looked at group differences, excepting gender and sometimes age. Most symbol-testing studies have relied solely on college students as participants. However, there are exceptions, e.g., Hoonhout (2000) and Silver et al. (1998). The present study is also an exception in this way by using different population groups. There are several reasons for using participants from different population groups. One is that it is simply more appropriate to test different groups of people who may be targets of symbol communication. Another related reason is for greater generality, the purpose is to reach target audiences for symbols who may encompass a wide range of people who may be at risk for particular hazard(s) represented by the symbols.

1.1. Research goals and rationale

The main goal of the present research was to evaluate a set of 17 safety signs to be used in workplaces, public areas and labels for dangerous substances currently in use in Portugal, European Union and many other countries around the world. The signs are presented as signboards, which are a combination of shape, color and symbol.

The focus was on the single-panel symbol-only format without a textual component. For the ISO symbol system, the intention is to communicate a message through a combination of symbol, a surround shape, and color codes. Many ANSI-formatted warnings lack symbols and instead rely solely on the use of a textual message. When text is absent from an ANSI warning, the symbol-only warning (which usually lacks a surround shape, although there may be a color code associated with the required signal word panel) must meet established comprehension criteria defined as 85% correct comprehension with fewer than 5% critical confusions. A critical confusion is generally defined as an answer opposite to the intended meaning, or other responses that may lead to injury.

The present research evaluates graphical symbols to determine if they reach acceptable levels of comprehension according to criteria defined by the ISO/TC 145 standard, i.e., 67% correct comprehension. This type of signs are not simply comprised of symbols. They also contain shape and color-coding to indicate type and degree of hazard and these components are also subject to potential problems of misinterpretation. Thus, a second purpose was to evaluate comprehension of color and surround shape configurations that are found in symbol-based signs. A third purpose was to assess participants' reported compliance intentions vis-à-vis the set of warning signs. A fourth purpose was to compare the comprehension and compliance intention scores from different groups of potential users. Specifically, participants were recruited from three groups: non-student adult-workers (AW), college students (CS), and persons with cerebral palsy (CP). The inclusion of disabled persons with CP and the non-student adult group was also intended to increase the generalizability of the findings. A final purpose was to examine the relationships between participant symbol comprehension performance, participant demographics (i.e., age, gender), and individual/experience variables (i.e., education level, previous experience with computers, have a driver's license). Previous experience with computers was considered because many computer operating systems use icons and symbols to convey designations and functions. Therefore, participants with such experience might be more "attuned" and familiar with graphical representations. As for the driver's license, this variable was considered because most of the ISO-type safety signs follow a similar system of shape–color code in traffic signs. Therefore, it was expected that experienced computer users and those with a driver's license would perform better on sign comprehension and compliance. Additionally, participants' familiarity with the signs was assessed (Hancock et al., 2004; Ng and Chan, 2007).

Some disabled persons, such as individuals with CP, may have difficulty verbalizing and/or coordinating body movement. Thus, writing or even speaking may limit performance when warning signal comprehension tests involve those tasks (Leonard et al., 1999). When developing warnings for the general public, Wogalter et al. (1999) stress the importance of including persons in the lower extremes in the sample of likely users when these warnings are subjected to testing. This last point is reinforced by studies that have shown that there are symbols that are not well understood even by highly literate and educated users (Lim et al., 2000; Ringseis and Caird, 1995), thus it can be reasonably expected that persons with limited cognitive skills would have difficulty comprehending them (Mishra, 1982; Mishra and Gupta, 1983). Many persons with CP and other disabilities are able to work, depending on their degree of disability. Like other persons in the workplace, disabled persons such as those with CP may be exposed to dangerous conditions and need well-designed communications to warn them.

2. Method

2.1. Participants

A total of 90 volunteers were recruited at various public meeting places in Lisbon, Portugal, including universities, factories, offices and disabled person's support centers. All participants were native Portuguese speakers with no uncorrected vision problems. The groups were:

- Adult workers (AW): Employed workers ranging in age from 21 to 62 years, mean age = 43.6 (*SD* = 9.89), 13 males, 17 females.
- College students (CS): Students, ranging in age from 18 to 28 years, mean age = 21.70 (*SD* = 2.2), 11 males, 19 females.
- Cerebral palsy (CP): Persons having the medical condition of cerebral palsy, ranging in age from 16 to 53 years, mean age = 33.2, (*SD* = 10.58), 21 males, 9 females.

The three groups differed in the level of education attained. Approximately two thirds of the AW group graduated high school; about half of these individuals attained a graduate degree. All of the CS participants were second-year design students from two universities in Lisbon, Portugal. Only one member of the CP group graduated high school and another one attained a graduate degree.

Table 1 shows the percentage of participants in each group who reported that they use computers and the Internet, and reported having a driver's license.

Table 1
Percentages of persons who reported computer usage, Internet usage, and have driver's license, by participant group.

Affirmative answer (Yes)	Adult workers (AW) (%)	College students (CS) (%)	Cerebral palsy (CP) (%)
Computer usage	60.0	93.3	66.7
Internet usage	40.0	93.3	56.7
Have driver's license	86.7	73.3	3.3

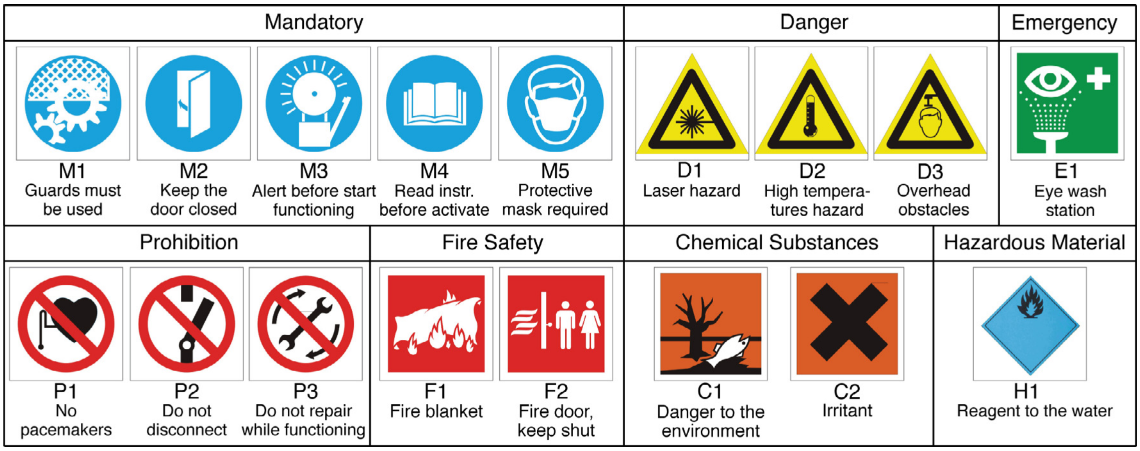


Fig. 1. The set of safety signs used in the experiment.

2.2. Materials

2.2.1. Sign selection

Safety signs for a varied range of hazard types were included to foster greater generalizability of the test results.

Six experts (three males, three females) participated in the safety sign selection process. All were academic instructors, in ergonomics and design. A total of 17 signs were used in the study. All came from various Internet sources (e.g., symbol collections available online). Sixteen were selected to fit the following criteria: be of certain type and purpose (e.g., mandatory, prohibition); have one or more aspects of poor design qualities, such as complexity illegibility, poor quality depiction; and infrequently used. Thus, 16 of the signs depicted the intended concept poorly and/or were infrequently used, so would likely be relatively unfamiliar to most of the participants. The 17th sign (M5), that the judges determined would be relatively easy to understand, served as a comparison benchmark relative to the other signs.

The signs possessed features consistent with ISO3864-1 (2002) standard, Dangerous Substances Directive (DSD) 67/548/CEE (EEC, 1967) and United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS, 2005) in that they combined symbolic forms, color and a shape code. The experts were asked to provide (in writing) the reasons for their safety sign recommendations. Each expert performed the task independently, and the entire safety sign selection procedure took approximately 1 h. Fig. 1 shows the final set of safety signs and their respective intended meanings.

The final set of signs comprised two basic types of applications: environments and facilities (ISO, 2002) and, on dangerous substances labels (EEC, 1967, GHS, 2005). The United States has a standard with similar categories of signs but use different designs which incorporate a signal word panel and message text (ANSI Z535.2, 2007a). Also, the signs reflected a range of ISO warning types including the categories of mandatory, emergency, prohibition, danger, and fire safety.

2.2.2. Environmental context photographs selection

Previous research (e.g., Wolff and Wogalter, 1998) has shown that providing a context in which symbols may occur in real-world settings can significantly enhance levels of comprehension as compared to no or little context. A photograph illustrating a likely context of use for each safety sign was included as part of the test stimuli, placed adjacent to the safety sign. The photographs were obtained from the Internet and their selection involved the following rules: (1) photographs showed an environment rather than a person, but if a person was shown, that person was not engaged in the prohibited or suggested behaviors; and (2) photographs illustrated a probable place where the sign could be displayed.

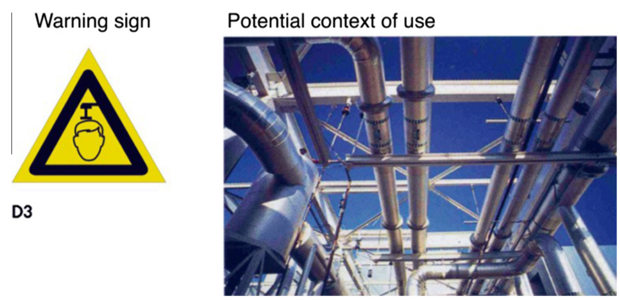


Fig. 2. Test page with photographic context.

2.2.3. Equipment

Fig. 1 shows the final set of 17 safety signs. Five signs depicted mandatory actions (category M); one was an emergency sign (category E); three depicted prohibited actions (category P); three depicted dangers (category D); two concerned fire safety (category F); two were chemical substances labels (category C)[4] and one was used for hazardous material transportation (category H). The signs were printed as color photographs (approximately 6×6 cm in size), with the words “Safety Sign” printed atop each sign. Each sign was printed on a separate sheet of A4 white paper, alongside the contextual photograph labeled with the words “Potential context of use” printed above the photograph. Fig. 2 shows an example.

2.3. Procedure

The basic method of assessment was open-comprehension testing as described in ISO (International Organization for Standardization) 9186 (2001) and in ANSI (American National Standards Institute) Z535.3 (2007b). Participants were tested individually and there was no established time limit to complete the task. Upon arrival, participants completed an informed consent form. Then each participant was told about the task.

[4] The classification and labelling of chemicals in Europe is changing. The new symbols being proposed by CLP (Classification, Labelling and Packaging) Regulation are taken over from the United Nations GHS (Globally Harmonized System). Since 1 December 2010, some substances and mixtures have already been labelled according to the new legislation, but the old symbols can still be on the market until 1 June 2017. As a consequence, some designs tested here (i.e., signs C1, C2) should no longer be in use after this date.

Each participant was given a questionnaire that consisted of two parts" Part 1 was comprised of questions about the set of safety symbols, while Part 2 requested demographic information and information concerning the participants' previous experience.

2.3.1. Questionnaire: Part 1

Signs and their respective probable context of use were displayed individually on 17 pages. The pages were randomly ordered for each participant. The researcher verbally asked the participant the following questions: (1) What do you think the sign means? (2) What action would you take in response to this safety sign? (3) Have you seen this symbol before? In addition to the verbal questioning, the questions were also printed on sheets that each participant could read at the same time. This procedure was suggested by ISO 9186 (2001) and was thus used in determining the comprehension correctness level in the present study. Participants gave oral answers for the entire experimental procedure. The sessions were videotaped. Prior to carrying out these tasks they participated in an initial practice trial with a sign and contextual photograph that were not part of the main experiment. The details of the practice trial are described later in this section.

Comprehension data were obtained separately for the pictorial symbols and the signs' background color and shape code. Compliance intentions for each sign were also assessed. These last two criteria are not addressed by the ISO 9186 (2001) standard. The criteria were developed because safety signs, in practice, comprise aspects beyond simply the symbol itself including the surrounding color and shape coding. Indeed, according ISO 9186 (2001), safety signs are messages combining color and geometric shape and which, by the addition of a graphical symbol, give a particular safety message. Knowledge of the effects of entire signs as well as the components is useful because it can influence safety sign interpretation. For example, people may understand the meaning of the symbol but not the color and shape coding and thus fail to understand the relative urgency intended (or vice versa), and from this people might behave with inappropriate cautiousness. In an early study, Riley et al. (1982) found that shapes that appear unstable (e.g., equilateral triangle pointing downward and a square on its vertex) are preferred for warnings.

Three independent judges individually scored all participant responses. One judge was the first author, and the other two were graphic/communication design professors. While doing the scoring, the judges had each symbol's intended meaning and the participant's written and videotaped responses. If the three judges were unable to agree on the judgment for a response, the score reported by two of them was used in the analysis. The inter-rater reliability of the scoring (percentage of scores matching between the three judges) was 78.2%.

Correctness of comprehension of meaning of pictorial symbol was determined based on the following seven standard categories suggested by the ISO 9186 (2001):

(1) Correct understanding of the symbol meaning is certain (estimated probability of correct understanding over 80%).
(2) Correct understanding of the symbol meaning is very probable (estimated probability of correct understanding between 66% and 80%).
(3) Correct understanding of the symbol meaning is probable (estimated probability of correct understanding between 50% and 65%).
(4) The meaning which is understood, is opposite to that intended.
(5) Any other response.
(6) The response given is "don't know".
(7) No response is given.

The shape–color assessment tested participants' comprehension of the shape–color background meaning (separate from the symbol). A criterion used for symbol comprehension testing was adapted to fit the role of measuring participants' interpretation of the shape–color meanings. The shape–color code was assessed relative to the following:

- Prohibition: Round shape; black symbol on white background, red edging and diagonal line.
- Danger: Triangular shape; black symbol on yellow background with black edging.
- Mandatory: Round shape, white symbol on blue background.
- Emergency: Rectangular or square shape, white symbol on green background.
- Fire fighting: Rectangular or square shape, white symbol on red background.
- Labels on chemical products: Square shape, black symbol on orange background with black edging.
- Transport of hazardous materials: square on its vertex, black symbol on a light blue background color (for the case of reagent to water substances).

This measure was assessed from the answers given to the question "What do you think the sign means?" Completely correct responses should include the meaning of the symbol and the shape–color code.

Critical confusions (category 4) were assessed by responses attributing the opposite meaning to the shape and color components. To illustrate, consider the common prohibition symbol. The information/instructions transmitted by this code are such that the sign prohibits a behavior likely to cause danger or place people at risk. If, however, it were interpreted as a behavior being allowed or even being beneficial to the user, then this misunderstanding would be a critical confusion. Evaluated were participants' answers to the question "What action would you take in response to this safety sign?"

The compliance intention evaluation was based on a rating scale that was adapted from the ISO 9186 rating scale:

(1) Correct compliance intention is certain (estimated probability of correct behavior intention over 80%).
(2) Correct compliance intention is very probable (estimated probability of correct behavior intention between 66% and 80%).
(3) Correct compliance intention is probable (estimated probability of correct behavior intention between 50% and 65%).
(4) The behavior intention is opposite to that intended.
(5) Any other response.
(6) The response given is "don't know".
(7) No response is given.

For the compliance intention evaluation, an example of a critical confusion would be if someone interpreted an exit sign as an entrance sign.

Prior to beginning the main tasks described above, participants were given an initial practice trial. Participants were shown an example sheet with a "No Smoking" sign and context and told to report what it meant. Regardless of their answer, they were given a complete and specific verbal explanation of the symbol's intended meaning, including the purpose of the accompanying contextual photo. The preliminary session ended when the participant had no further questions about the forthcoming experimental task.

2.3.2. Questionnaire: Part 2

Part 2 involved analyses of participants' background and experience. Information about age, gender, educational level, use of a computer on a daily basis and if they have a driver's license was requested. However, since the individuals in the CP group were generally unable to write, the researcher recorded their oral answers.

3. Results

3.1. Signs interpretation

Participants' responses about comprehension of meaning of pictorial symbol, comprehension of shape–color code and compliance intentions were scored using the previously described correctness categories.

The percentage of participants' responses obtained in the first three categories was multiplied by a factor of correction, described in ISO 9186 (2001), as follows:

(1) Correct understanding is certain – the percentage is multiplied by 1.
(2) Correct understanding is very probable – the percentage is multiplied by 0.75.
(3) Correct understanding is probable – the percentage is multiplied by 0.5.

The sum of these three values was labeled as "Score". The percentage of responses classified as opposite (category 4) was subtracted from the "Score" resulting in "Overall Score". The presence of negative scores is explained by the existence of high percentages of opposite meanings that were generated (i.e., critical confusions). Table 2 shows the overall scores for the three main dependent variables. Scores with bold/underline markings on the left side of Table 2 show the symbols that exceeded ISO's 67% correct comprehension criterion. The 5% criterion was also used in the shape–color comprehension and compliance intentions and they are also shown with bold/underline markings in the middle and right side of the table.

Table 3 shows that nine of the 17 signs generated at least some critical confusions (opposite answers). Scores with bold/underline markings on the left side of Table 3 show the particular signs that exceeded the ANSI acceptability level of attaining more than 5% critical confusions for symbol comprehension. The 5% criterion was also used in the shape–color comprehension and compliance intentions and they are also shown with bold/underline markings in the remainder of the table.

According to ANSI Z535.3, symbols that exceed the 5% critical-confusion level should be rejected. Based on ANSI Z535.3's critical confusion criterion of 5%, five symbols would be rejected based on

Table 2
Overall scores for comprehension of symbol meaning, shape–color, and compliance intention for the 17 signs by participant group.

Signs	Comprehension of symbol meaning			Comprehension of sign shape–color code			Compliance intention		
	AW	CS	CP	AW	CS	CP	AW	CS	CP
M1	30.00	21.67	4.17	24.17	26.67	−1.67	10.00	7.50	0.00
M2	55.83	65.00	17.50	41.67	**71.67**	26.67	50.00	64.17	21.67
M3	15.83	16.67	6.67	20.00	20.83	9.17	2.50	3.33	1.67
M4	50.00	50.00	25.83	30.00	35.83	0.83	36.67	35.00	13.33
M5	**82.50**	**91.67**	**69.17**	64.17	**75.00**	45.83	**79.17**	**95.00**	64.17
E1	8.33	15.00	−7.50	−3.33	3.33	−3.33	3.33	15.83	−11.67
P1	46.67	**70.83**	7.50	**78.33**	**87.50**	60.83	43.33	60.00	15.00
P2	1.67	0.00	0.00	**70.00**	**68.33**	**68.33**	1.67	1.67	0.00
P3	18.33	23.33	6.67	**72.50**	**88.33**	**69.17**	15.00	26.67	8.33
D1	42.50	51.67	16.67	45.00	59.17	45.83	30.00	44.17	20.00
D2	**75.83**	**87.50**	50.83	**70.83**	65.83	40.83	39.17	50.83	17.50
D3	39.17	31.67	10.00	**69.17**	64.17	40.00	50.83	53.33	27.50
F1	−23.33	−31.67	−4.17	3.33	5.00	0.00	−11.67	−8.33	2.50
F2	15.83	15.00	1.67	10.00	11.67	1.67	10.83	19.17	0.00
C1	65.83	62.50	38.33	25.00	19.17	17.50	38.33	29.17	13.33
C2	58.33	56.67	36.67	**96.67**	**95.00**	**98.33**	57.50	60.00	32.50
H1	**90.00**	**85.00**	**86.67**	−1.67	11.67	0.00	0.00	0.00	0.00

Note: Bold/underline values are the signs that reached the ISO acceptance criterion (67%). AW – Adult workers; CS – College Students and CP – persons with cerebral palsy. Letter codes for the sign categories are M for mandatory, E for emergency, P for prohibition, D for danger, F for fire safety, C for chemical substances label, and H for hazardous material transportation. Negative values stem from a high level of "opposite meaning" responses.

Table 3
Percentage of critical confusion errors (opposite answers) by participant group for the signs for which they occurred.

Signs	Adult workers (%)			University students (%)			Cerebral palsy (%)		
	CSM	CSC	CI	CSM	CSC	CI	CSM	CSC	CI
M1	3.33			3.33				**10.00**	
M2			3.33						
M4					3.33		**10.00**	**10.00**	**10.00**
E1		**6.67**	**6.67**	3.33	**6.67**	**6.67**	**10.00**	3.33	**13.33**
P2								3.33	
P3						3.33	3.33	3.33	3.33
D2						3.33			**6.67**
F1	**26.67**		**13.33**	**36.67**		**13.33**	**6.67**		
R1		3.33							

Note: CSM – Comprehension symbol meaning; CSC – comprehension of shape–color; CI – compliance intention. Bold/underlined scores are those whose value exceeds the 5% critical confusion level established by ANSI Z535.3.

symbol comprehension scores for one or more groups. These symbols were: M1 – Guards must be used, M4 – Read instructions before use, E1 – Eye wash station, D2 – High temperature hazards and F1 – Fire blanket.

Generally, the CP group had the largest number of critical confusions for the set of signs. Interestingly, the AW and CS groups had higher levels of critical confusions than the CP group for the F1 sign. This sign is intended to communicate a fire blanket. Several persons in the AW and CS groups interpreted it as burning (flammable), rather than its intended function to extinguish a fire, but this critical confusion occurred less often among participants of the CP group.

3.1.1. Comprehension of pictorial symbols

The distribution of the pictorial symbol comprehension scores in Table 3 shows that the set of signs included poorly understood ones (see Fig. 3).

Few symbols reached the 67% ISO comprehension criterion: (a) three symbols in the AW group (signs M5 – Protective mask required; D2 – High temperatures hazard; H1 – Reagent to the water), (b) four symbols in the CS group (signs M5 – Protective mask required; P1 – No pacemakers; D2 – High temperatures hazard; H1 – Reagent to the water), and (c) two symbols in the CP group (signs M5 – Protective mask required; H1 – Reagent to the water). Only two signs reached the understandability criterion across all three groups (M5 and H1). The pictorial symbols with the five highest and five lowest comprehension scores for each group are presented in Table 4.

The overall mean symbol comprehension scores across all 17 symbols were:

- AW group: 39.61% (SD = 30.84), ranging from −23.33 (min.) to 90.00 (max.).
- CS group: 41.91% (SD = 34.19), ranging from −31.67 to 91.67.
- CP group: 21.57% (SD = 26.66), ranging from −7.50 to 86.67.

The data show that the CS group attained a somewhat higher level of symbol comprehension than the two other groups, followed closely by the AW group. The CP group had the lowest comprehension scores. The overall mean comprehension for the symbols in the signs across participant groups was 34.36% (SD = 29.45), ranging from −19.72 to 87.22.

Friedman two-way analysis of variance by ranks test revealed that there was a significant effect of group in the scores of comprehension of symbol meaning, $\chi^2(2) = 16.64$, $p < .001$. Dunn–Bonferroni pairwise multiple comparisons indicated that both AW group (Median = 42.5, Interquartile Range (IQR) = 46.3; $p = .001$) and CS group (Median = 50.0, IQR = 52.1; $p = .002$) scored significantly

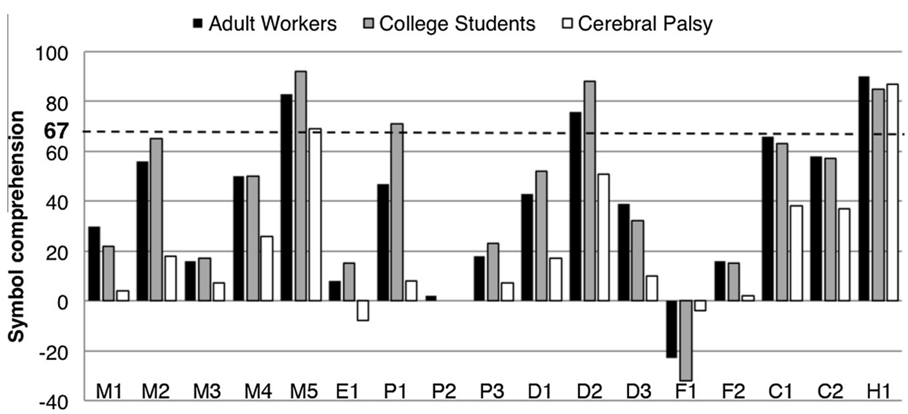
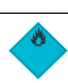
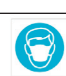
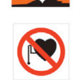
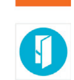
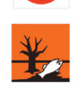
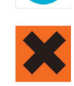
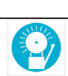
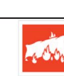
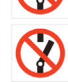
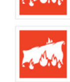
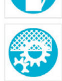
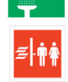
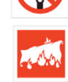


Fig. 3. Scores for comprehension of symbol meaning for the 17 signs by participant group.

Table 4
Five highest and five lowest symbol comprehension scores as a function of participant group.

	Scores for symbol comprehension									
5 Highest	1st		2nd		3rd		4th		5th	
AW		H1 90.00		M5 82.50		D2 75.83		C1 65.83		C2 58.33
CS		M5 91.67		D2 87.50		H1 85.00		P1 70.83		M2 65.00
CP		H1 86.67		M5 69.17		D2 50.83		C1 38.33		C2 36.67
5 Lowest	13rd		14th		15th		16th		17th	
AW		M3 15.83		F2 15,83		E1 8.33		P2 1.67		F1 −23.33
CS		M3 16.67		E1 15.00		F2 15.00		P2 0.00		F1 −31.67
CP		M1 4.17		F2 1.67		P2 0.00		F1 −4.17		E1 −7.50

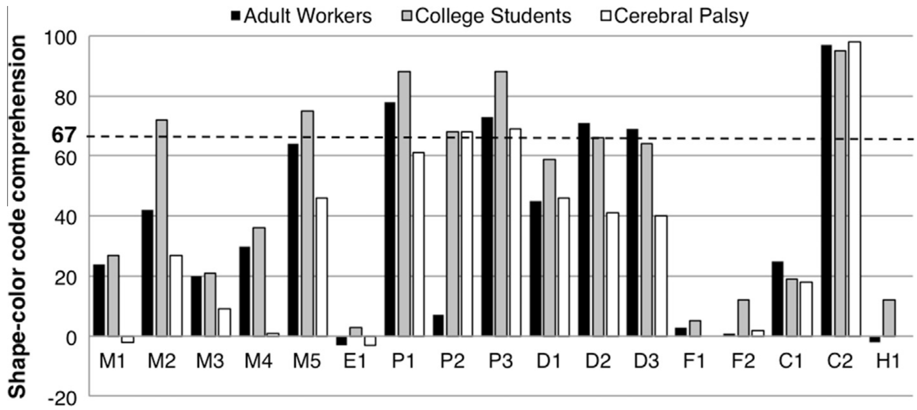


Fig. 4. Scores for comprehension of shape–color code for the 17 signs by participant group.

higher than CP group (Median = 10.0, IQR = 34.6); but there were no significant differences between the AW and CS groups.

3.1.2. Comprehension of shape–color code

Comprehension of the signs' shape–color coding was also examined. In the absence of any specific standard acceptability criteria, the 67% level (similar to the ISO symbol comprehension criterion) was used as the criterion to compare to the levels found in the present study. Fig. 4 demonstrates that several instances of the signs' shape–color coding were poorly comprehended.

Only five signs attained 67% comprehension criterion for shape–color in the AW group (signs P1 – No pacemakers; P3 – Do not repair while functioning; D2 – High Temperatures hazard; D3 – Overhead obstacles; C2 – Irritant). Six signs in the CS group attained the 67% correct comprehension criterion for shape–color (signs M2 – Keep the door closed; M5 – Protective mask required; P1 – No pacemakers; P2 – Do not disconnect; P3 – Do not repair while functioning; C2 – Irritant). Three signs in the CP group attained the 67% comprehension criterion for shape–color (signs P2 – Do not disconnect; P3 – Do not repair while functioning; C2 – Irritant). Thus only three signs (P2, P3 and C2) reached the 67% criteria across all three groups. The five highest and the five lowest signs shape–color code scores are presented in Table 5.

The mean shape–color code comprehension scores across all signs for each of the three participant groups were:

- AW group: 42.11% (SD = 31.43), ranging from −3.33 to 96.67.
- CS group: 47.60% (SD = 32.07), ranging from of 3.33 to 95.00.
- CP group: 30.59 (SD = 31.13), ranging from −3.33 to 98.33.

The CS group attained the highest mean, followed closely by the AW group. Again, the CP group had the lowest comprehension mean. The overall shape–color code comprehension mean for all signs and groups was 40.10% (SD = 30.83), ranging from −1.11 to 96.67.

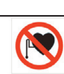
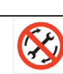
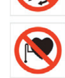
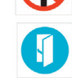
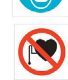
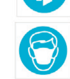
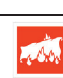
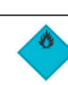
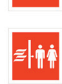
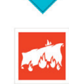
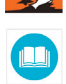
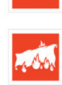
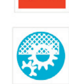
Friedman two-way analysis of variance by ranks test revealed a significant effect of participant group for shape–color code comprehension, $\chi^2(2) = 15.55$, $p < .001$. Dunn–Bonferroni pairwise multiple comparisons indicated that the CS group (Median = 59.2, IQR = 57.9) scored significantly higher than the CP group (Median = 26.7, IQR = 52.9; $p < .001$); however, there were no significant differences between the AW group (Median = 41.7, IQR = 55.4) and the CS and CP groups.

3.1.3. Compliance intentions

Fig. 5 depicts the compliance intention accuracy across the three groups.

The score of 67% was reached only by one sign (M5 – Protective mask required) by the AW and CS groups. No sign achieved the 67% score in the CP group on compliance intention accuracy. Signs with the five highest and the five lowest compliance intention scores for each group are presented in the Table 6.

Table 5
Five highest and five lowest shape–color code comprehension scores as a function of participant group.

Scores for shape-color code comprehension										
5 Highest	1st		2nd		3rd		4th		5th	
AW		C2 96.67		P1 78.33		P3 72.50		D2 70.83		P2 70.00
CS		C2 95.00		P3 88.33		P1 87.50		M5 75.00		M2 71.67
CP		C2 98.33		P3 69.17		P2 68.33		P1 60.83		M5 45.83
5 Lowest	13rd		14th		15th		16th		17th	
AW		M3 20.00		F2 10.00		F1 3.33		H1 −1.67		E1 −3.33
CS		C1 19.17		F2 11.67		H1 11.67		F1 5.00		E1 3.33
CP		M4 0.83		F1 0.00		H1 0.00		M1 −1.67		E1 −3.33

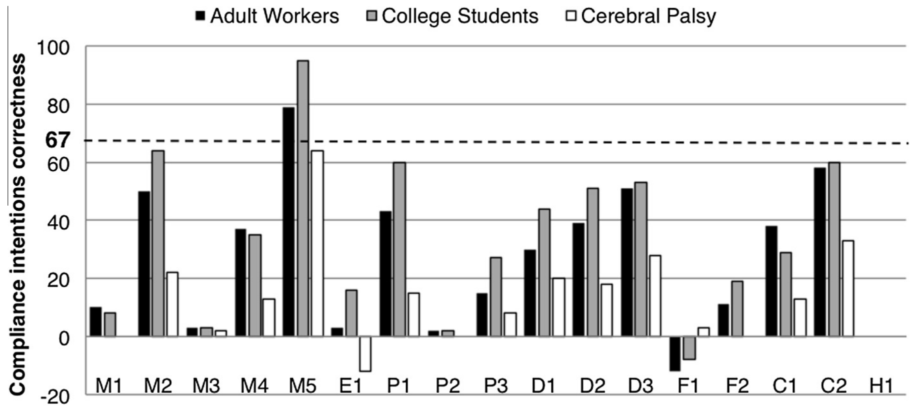
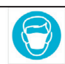
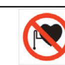
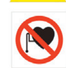
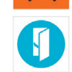
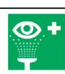
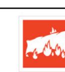
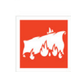


Fig. 5. Scores for compliance intentions accuracy for the 17 signs by participant group.

Table 6
The five highest and five lowest compliance intentions scores as a function of participant group.

Scores for compliance intentions correctness					
5 Highest	1st	2nd	3rd	4th	5th
AW	 M5 79.17	 C2 57.50	 D3 50.83	 M2 50.00	 P1 43.33
CS	 M5 95.00	 M2 64.17	 P1 60.00	 C2 60.00	 D3 53.33
CP	 M5 64.17	 C2 32.50	 D3 27.50	 M2 21.67	 D1 20.00
5 Lowest	13rd	14th	15th	16th	17th
AW	 E1 3.33	 M3 2.50	 P2 1.67	 H1 0.00	 F1 −11.67
CS	 M1 7.50	 M3 3.33	 P2 1.67	 H1 0.00	 F1 −8.33
CP	 M1 0.00	 P2 0.00	 F2 0.00	 H1 0.00	 E1 −11.67

The mean scores, across all 17 signs were:

- AW group: 26.86% (SD = 25.14), ranging from −11.67 to 79.17.
- CS group: 32.79% (SD = 28.49), ranging from −8.33 to 95.00.
- CP group: 13.28% (SD = 18.50), ranging from −11.67 to 64.17.

The CS group had the highest overall compliance intention mean; the CP group had the lowest. For all signs and all groups the mean was 24.31% (SD = 23.12), ranging from −5.83 to 79.45.

Friedman test revealed that there was a significant effect of group in the scores of compliance intentions ($\chi^2(2) = 21.24$, $p < .001$). Dunn–Bonferroni pairwise multiple comparisons indicated that the AW group (Median = 30.0, IQR = 43.8; $p = .014$) and CS group (Median = 29.2, IQR = 51.3; $p < .001$) scored significantly higher than CP group (Median = 13.3, IQR = 20.8). No significant differences were found between AW and CS groups.

3.2. Reported having seen signs

Table 7 shows the percentage of persons in each group who reported having seen each sign previously. It is an indication of sign familiarity. The observed values ranged from 0% to 100%. The majority of the signs evaluated were reportedly new to the participants. These are, of course, self-report measures, and thus some

Table 7
Percentage of participants that reported having previously seen the signs as a function of participant group, and the overall mean and standard deviation. Percentage of participants reporting having previously seen the signs.

Signs	M1	M2	M3	M4	M5	E1	P1	P2	P3	D1	D2	D3	F1	F2	C1	C2	H1
AW	6.7	**16.7**	0.0	3.3	50.0	3.3	0.0	0.0	0.0	6.7	**30.0**	6.7	**10.0**	3.3	10.0	96.7	43.3
CS	0.0	3.3	**3.3**	6.7	**60.0**	3.3	**6.7**	0.0	0.0	**13.3**	13.3	0.0	3.3	0.0	6.7	**100.**	**60.0**
CP	**13.3**	13.3	**3.3**	**16.7**	36.7	**6.7**	3.3	**3.3**	**10.0**	10.0	20.0	**10.0**	**10.0**	**30.0**	**13.3**	83.3	50.0
Mean	6.7	11.1	2.2	8.9	48.9	4.4	3.3	1.1	3.3	10.0	21.1	5.6	7.78	11.1	10.0	93.3	51.1
SD	6.7	6.9	1.9	6.9	11.7	1.9	3.3	1.9	5.8	3.3	8.4	5.0	3.9	16.4	3.3	8.8	8.4

Note: For each sign, the higher percentage is marked as bold/underline.

Table 8
Spearman's rank-order correlations between signs comprehension, compliance intention and familiarity, by participant group.

	Comprehension of symbol meaning	Comprehension of shape–color	Compliance intention
Adult workers group			
Comprehension of shape–color	.27		
Compliance intention	.59*	.65**	
Familiarity	.35	.23	.02
College students group			
Comprehension of shape–color	.45		
Compliance intention	.68**	.69**	
Familiarity	.69**	−.12	.20
Cerebral palsy group			
Comprehension of shape–color	.25		
Compliance intention	.60*	.60**	
Familiarity	.67**	−.05	.30

** $p < .01$.
* $p < .05$.

caution is warranted since these reports may not accurately reflect what participants have actually experienced.

The percentage of participants that reported having seen the signs were:

- AW group ranged from 0% to 96.67%, mean = 15.88% (SD = 24.26).
- CS group ranged from 0% to 100.00%, mean = 16.47% (SD = 28.64).
- CP group ranged from 3.33% to 83.33%, mean = 19.60% (SD = 20.67).

A Friedman test did not find significant differences among groups for having seen the signs (AW: Median = 6.7, IQR = 21.7; CS: Median = 3.3, IQR = 10.0; CP: Median = 13.3, IQR = 16.65; $\chi^2(2) = 4.939$, $p = .084$).

Spearman's rank-order correlations were carried out, in each group, to evaluate if there were significant correlations among the measures of symbol and shape–color code comprehension, compliance intention and familiarity. There were several moderate positive correlations between some dependent variables. Notably there were no significant correlations between pictorial–symbol meaning and shape–color code comprehension. There were also no significant correlations between the shape–color code comprehension and the familiarity or between compliance intention and familiarity. These results are shown in Table 8.

3.3. Individual and experience variables

3.3.1. Age and gender

Gender and age groups (coded into three categories: 1 = less than or equal to 21 years; 2 = aged 22–35 years; 3 = greater than or equal to 36 years) differences were examined. Chi-square tests for homogeneity with a Bonferroni correction did not show any significant differences for these two variables with respect to the main experimental measures.

3.3.2. Education level

Regarding education level (coded as 1 = up to middle school; 2 = high school; 3 = college), the Chi-square tests for homogeneity with Bonferroni correction revealed that there were a few significant differences:

i. Comprehension of pictorial–symbol meaning for sign M2 ($\chi^2(6) = 27.25$, $p = .005$); for sign P1 ($\chi^2(6) = 38.51$, $p < .001$); for sign D3 ($\chi^2(6) = 24.57$, $p = .008$); and for sign C1 ($\chi^2(6) = 25.32$, $p = .004$).
ii. Comprehension of sign shape–color code for sign M2 ($\chi^2(6) = 26.55$, $p = .003$).
iii. Compliance intention for sign P1 ($\chi^2(6) = 21.68$, $p = .025$).

For these listed significant differences, participants with a lower education level were less likely to score the first category of correctness (i.e., correct understanding is certain) and were more likely to score the fifth category (any other response) than participants with a higher education level. The CP group had the lowest educational levels.

3.3.3. Computer usage

For computer usage (high versus low), the Chi-square tests for homogeneity with Bonferroni correction showed that there were significant differences for:

i. Comprehension of pictorial–symbol meaning for sign M2 ($\chi^2(6) = 15.63$, $p = .025$).
ii. Comprehension of sign shape–color code for sign P1 ($\chi^2(6) = 22.70$, $p < .001$).
iii. Compliance intention for sign M5 ($\chi^2(6) = 14.58$, $p = .037$).

For these listed significant differences, participants with computer usage were more likely to score in the first category of correctness (correct understanding is certain) than participants without computer usage, and participants without computer usage were more likely to score the fifth category (any other response) than participants with computer usage. The AW group has the lowest computer usage levels.

3.3.4. Driver's license

With respect to driver's license (has one versus does not have one), the Chi-square tests with Bonferroni correction indicated that there were significant differences in the distribution of:

i. Comprehension of pictorial–symbol meaning for sign M1 ($\chi^2(3) = 15.16$, $p = .017$); for sign M2 ($\chi^2(3) = 18.03$, $p = .003$); for sign C1 ($\chi^2(3) = 28.84$, $p < .001$); and for sign D3 ($\chi^2(3) = 15.04$, $p = .012$).
ii. Comprehension of sign shape–color code for sign M1 ($\chi^2(4) = 15.83$, $p = .015$); for sign M2 ($\chi^2(3) = 22.83$, $p < .001$); for sign M5 ($\chi^2(4) = 23.15$, $p < .001$); and for sign D3 ($\chi^2(4) = 15.87$, $p = .014$).
iii. Compliance intention for sign M2 ($\chi^2(4) = 19.77$, $p = .002$); and for sign P1 ($\chi^2(4) = 17.40$, $p = .004$).

For these significant differences, participants with a driver's license were more likely to score the first category of correctness (correct understanding is certain) than participants without a driver's license. Participants without a driver's license were more likely to score in the fifth category (any other response) than participants with a driver's license. For comprehension of shape–color code for signs M1 and M2, findings indicated that participants with a driver's license were more likely to score in the second category of correctness (correct understanding is very probable) than participants without a driver's license. Most of the persons without a driver's licenses were from the CP group.

4. Discussion and conclusions

Most of the safety signs evaluated in this study were poorly understood by participants. Regardless of group membership, many participants were unfamiliar with most of the signs, and did not understand their meaning via the symbol or shape–color code components. A similar pattern in the intended compliance results was also noted.

The CS group attained and surpassed the ISO acceptability criterion of 67% correct symbol comprehension for only four of the 17 signs tested. Only three and two signs reached this criterion by the AW and CP groups, respectively. Thus, most of the symbols would fail when evaluated according to the ISO symbol comprehension criterion. The symbol achieving the highest comprehension level, the M5 – Protective mask required symbol, was an image illustrating, in a clear, direct and representational way, a face with a mask. The judges had selected this symbol as the only one that would likely reach high levels of comprehension, and it did so relative to the rest of the set of signs. Another sign that performed well was "High temperatures hazard" (D2). Its high level was somewhat surprising since the judges who selected the signs for this study considered it to be unfamiliar, illegible and/or a poor quality depiction.

Overall, the data indicate a need to redesign most of the symbols in the set to make them more understandable. Analysis of the participants' responses can be helpful toward this end. Consider the fire blanket symbol (F1); according to participants' responses, it was least able to convey its intended concept. The incorrect verbal responses indicated that several participants thought it depicted something burning (or flammable), rather than indicating its purpose in extinguishing a fire. With this kind of wrong response, the symbol recorded high levels of critical confusions, particularly by the AW and CS groups. Other examples include "Eye wash station" (E1) and "Do not disconnect" (P2). For the "Eye wash station" symbol, the low scores appeared to be due to stimulus complexity (needing several graphic components to transmit the concept). The "Do not disconnect" symbol represented a technical or engineering concept that many of the participants may not have been familiar with (Wogalter et al., 2006). In general, the symbol comprehension results, as shown by low performance on signs P2, E1, and M3 compared to high performance on M5, D2, and H1, support the notion that concrete, specific symbols are better comprehended than abstract, general symbols (Davies et al., 1998; Silver and Perlotto, 1997).

Shape–color code comprehension acceptability criterion, using a benchmark similar to ISO's 67% symbol comprehension, was attained in six signs by both CS and AW groups and in three signs by the CP group. The best understood signs were in the categories of prohibition (e.g., P1 – No pacemakers; P2 – Do not disconnect; P3 – Do not repair while functioning), followed by dangerous environmental conditions (e.g., D2 – High temperatures hazard; D3 – Overhead obstacles), and the chemical substances labels (e.g., C2 – Irritant). These results concur with previous findings showing that color and shape surround do not have a large effect on comprehension measures relative to other aspects of signs, e.g., symbols (Bresnahan and Bryk, 1975) or on compliance (Jaynes and Boles, 1990). Results suggest that prohibition and danger shape–color codes are better comprehended than the others codes.

For the compliance intention measure, only one sign – "Protective mask required" (M5) attained the ISO criterion by both CS and AW groups; none were attained by the CP group. Furthermore, five signs attained more than 5% opposite answers (critical confusions) in at least one of the three measures (symbol meaning, shape–color code meaning, and compliance intention) in at least one participant group.

Overall, participants reported low levels of familiarity with the signs. A significant positive relationship was found between symbol comprehension and familiarity in the CS and CP groups, but not in the AW group. No significant correlation was found between familiarity and shape–color-code comprehension or compliance intentions. There was no correlation between comprehension of the symbols and the shape–color code. This suggests that they are different, possibly independent dimensions. This result could be interpreted as the two components as potentially giving different information about the signs.

The criteria of 67% or 85% are simply adopted criteria that encourage additional efforts to attain sufficiently high comprehension levels if initial testing reveals that a symbol performs poorly. These particular levels or criteria are partly based partly on how scores are determined from the raw open-ended comprehension data, but also because of economics and effort. Redesign is time-consuming and costly to carry out. Attaining 100% comprehension is extremely difficult in practice. A somewhat lower criterion level keeps the costs reasonable. However, there is also a problem associated with the use of lowered comprehension-level criteria. Some signs may just reach the criterion (e.g., 68% accuracy) and thus no efforts are taken to redesign them as a result, even though further refinements could raise the correct comprehension even higher. After all, 68% correct symbol comprehension means that 32% of persons tested got it wrong! If it can be accomplished easily and economically, those refinements should be conducted to enable the sign to convey the intended message to even more people. In light of this, the data for symbols that attained high scores for symbol comprehension (above the ISO 67% criterion) were examined with respect to the responses scored as errors. If there were clear patterns in these data, then "unclear" but acceptable symbols might benefit from redesign. Consider the signs "Reagent to water" (H1) and "Irritant" (C2). Many participants were able to understand the symbol component (showing flames, flammable) in the symbol for "Reagent to water" (H1), but they did not know what the diamond shape in blue meant, which resulted in low scores for shape–color code and compliance intention. Also, the "Irritant" (C2) sign was considered "unclear" even though it attained high shape–color code scores but performed poorly when judged according to other criteria. This sign was reported as having been seen more than the other signs across all three participant groups, with percentages close to 100%. This could be due to it being the most salient of the signs with its bold lines and a large patch of red color, which would stand out in most products on which it was placed, and thus noticed frequently when given, but many people did not know what it meant. Thus, while a symbol's testing may demonstrate that it adequately met ISO requirements, it may not be as good as it could be, or as it should be.

Consistent with expectations, there were differences in sign performance as a function of participant group. Comprehension rates were significantly lower for the CP group but there were no differences between the CS and the AW groups. This concurs with several studies that show that other differently-abled individuals having different comprehension levels compared to other groups (Hoonhout, 2000; Mishra and Gupta, 1983; Silver et al., 1998). Despite the generally lower scores obtained by the CP group, the patterns of comprehension for the "good" and "bad" signs were generally similar across all three groups.

There were relatively few person-related differences as a function of the signs and the measures that were taken. There were no differences for age or gender for any sign. Participants with a driver's license were more likely to comprehend some signs (mostly in the mandatory category) than participants without a driver's license. There were some small differences in the sign performance measures with respect to computer usage, but the resulting pattern of results were not readily interpreted. The finding of limited relationship to these person-related variables is consistent with other findings (e.g., Choong and Salvendy, 1998; Smith-Jackson and Wogalter, 2000; Wogalter et al., 1997a).

A new aspect of the methodology was the evaluation procedure used to measure shape–color (background) code meaning. This methodology allowed for the examination of both symbol and its shape–color background. The methodology employed could be useful for other researchers in this area. A similar kind of measure was developed and used for compliance intentions. The open-ended comprehension test revealed that, in some cases, participants were able to correctly understand the meaning of the symbol, but failed to understand the meaning of the shape–color codes or vice versa. The correlational analyses suggest that the two comprehension measures are unrelated. This suggests that evaluation procedures in the future should consider both the symbol and the background code. Currently there are no available standards or evaluation guidance on comprehension of shape–color code. Future research might consider the development of a single score of comprehension success that merges the symbol and color–shape background.

The individuals with CP disability provided a unique and important contribution to this study. Despite the difficulties exhibited by the cerebral palsy group in answering orally to the open-ended questions, all of the CP participants managed to complete all of experimental procedures adequately. Because the testing procedure involving oral responses to visual stimuli required relatively low effort it can probably be used in further research with other differently-abled participant groups. These other groups could provide useful input into the development or redesign of safety signs so that the intended messages are understood by more people regardless of their abilities, knowledge or impairments. A similar pattern of scores across the three population groups (albeit the CP scores were in general lower) suggests that there may some generality to the findings. Moreover, the consistent pattern shown by the college students compared to the other two groups also indicates that data derived from testing with college students may not be as limited and as irrelevant as some critics have suggested.

One of the main purposes of symbols is to convey safety information, yet this study and other studies have found relatively low comprehension performance for existing, currently used symbols and color–shape surround. The finding of relatively low comprehension begs the question about how improved performance can be achieved. One way is to train people on the meaning of these graphical components. Research has shown that symbol comprehension can be improved with training (e.g., Lesch et al., 2011; Mishra and Gupta, 1983; Wogalter et al., 1997b). However, training programs are costly to develop and implement, perhaps most importantly, they are unlikely to reach everyone who needs to be trained and who may be at risk even with extremely high cost expenditures to do so. It is much better to disseminate signs that are understandable to varied target audiences without specific training. This means more effort is needed at the earlier design and re-design stages so that symbols are understood without costly training. Even the studies that show positive effects of training (e.g., Cairney and Sless, 1982; Wogalter et al., 1997b) show that poorer symbols are more resistant to simple, one-trial training. Although some training may be inevitable because some concepts are not amenable to clear symbolic depictions, overall training costs would likely be reduced if the symbols are understandable.

Sign components were not manipulated independently. Further work is necessary to distinguish individual effects of the sign components and to determine their relative contributions and possible interactions (Wogalter et al., 1997b). Additionally, the particular photographic context that was used could have influenced the findings. Contexts depicting a different environment or product might possibly evoke different meanings attributed to the signs. Additional research could examine how varied contexts can potentially change sign interpretation.

Clearly, comprehension of conventional symbol signage is not at levels that they should be. The goal of high levels of comprehension is important because the intention is (or should be) to communicate important safety information so that persons at risk of injury and property damage are not harmed. This means that it is improper to use symbols that do not result in people understanding them after purposely looking at them. There may be laws and standards that mandate the use of certain symbols in certain circumstances. However, even with the requirement to use a particularly poor symbol, it does not mean that additional more comprehensible signs cannot be used in addition to (and sometimes instead of) a required symbol. In other words, unless there are particular laws that prohibit additional, better safety signage, then they might be added to ensure adequate comprehension of the safety information by persons at risk. Thus it may be possible to place additional understandable safety messages with or in the same general area to compensate for a relatively poorly comprehended required sign. Clearly symbols need to be continually updated because cultural norms change over time and because better symbols have been found to do the job more effectively. Change is also a fundamental property and a particularly important issue in warnings because people tend to ignore repeated visual images over time, and thus, some revised and improved symbols would have a benefit and opportunity to better capture attention after habituation has taken place.

Error responses given by the participants were examined in order to highlight problematic design issues. These aspects may be responsible for the low performance shown by some of the signs. Again, further efforts should also be directed at refining the design of these and other safety signs.

In sum, the results demonstrate serious weaknesses in this set of currently used symbol-based signs. Some weaknesses were expected, however, because the set was pre-selected by judges as having one or more problems such a familiarity, legibility, and depiction quality. Clearly, most of these signs need to be redesigned if they are to serve their intended purpose of safety promotion. Although all of the participants in this research were residents in Portugal, the levels of comprehension are likely to be similar to persons living elsewhere in Europe or in other places around the world where the ISO type signs are commonly used. If these signs had been tested in the USA, where ISO type signs are uncommon, we would expect performance with this set of signs to be even lower than was found in this study.

Practitioners should not erroneously assume that frequently-used, standard signs are serving their purpose of warning people about hazards and promoting compliance. Designers should do the initial development work to make sure the signs they design are understandable. This should entail comprehension assessments with participant samples and a redesign processes as needed so that in application the symbols capably communicate important safety information to varied populations at risk.

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