Ergonomic Guidelines for Traffic Sign Design Increase Sign Comprehension

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Objective: This research directly tests the relationship between comprehension probability of highway signs and the extent to which they comply with three ergonomic principles of design: sign-content compatibility, familiarity, and standardization. **Background:** A recent study that evaluated comprehension of traffic signs in four different countries showed that comprehension level varies widely and is apparently related to the extent that the sign's design incorporates ergonomic guidelines for good design (D. Shinar, R. E. Dewar, H. Summala, & L. Zakowska 2003). **Method:** Participants were presented with 30 signs and asked to describe each sign's meaning. They then evaluated each sign in terms of each of three ergonomic principles. In addition, a group of human factors/ergonomics experts evaluated each sign on its standardization and compatibility. **Results:** There were high correlations between the ratings of the students and the ratings of the experts on compatibility (rho = .94) and on standardization (rho = .84), validating the use of the students' evaluations of the signs on these variables. There was a great variability in signs' comprehension and high and statistically significant correlations between the comprehension level of each sign and the extent to which it complied with compatibility ($R = .76$), familiarity ($R = .89$), and standardization ($R = .88$) principles. **Conclusions:** The more signs conform to universal ergonomic principles of good design, the more likely they are to be comprehended by drivers of different cultural backgrounds. **Application:** Sign design should be guided by established ergonomics principles to enhance comprehension, especially for drivers who have not had any prior encounters with specific signs.

INTRODUCTION

Traffic signs represent one of the most common devices for controlling traffic in that they help regulate, warn, and guide road users. In spite of their importance, traffic signs are not always clear to the drivers. Previous studies have found that comprehension varies widely among different highway traffic signs symbols. In a multicountry research, which included five Arabic countries, it was found that drivers understood only about 55% of the 28 signs presented to them (Al-Madani & Al-Janahi, 2002). In another study conducted in Canada, Dewar, Kline, and Swanson (1994) found that even some local signs were recognized by only about 40% of the drivers.

In a recent cross-cultural study, Shinar, Dewar, Summala, and Zakowska (2003) compared sign comprehension of drivers in four different countries with moderate to high levels of motorization: Canada, Finland, Israel, and Poland. The study evaluated the comprehension of highway traffic signs (with only symbols and no text on them) used in the different countries and attempted to identify the elements that might affect comprehension level. The issue of comprehension level of signs used in different countries is critical in this time of globalization because a driver licensed in one country may rent a car and drive in almost any other country, seeing signs that may be very different from those previously encountered. It was found across all countries that there are large differences among signs in their comprehension by the drivers. Some of the signs were fully

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understood by over 90% of the drivers, whereas others were not understood at all or understood by only a small percentage of the drivers. The study also showed that the comprehension level of older drivers (65+ years old) was lower (especially in Israel) than the comprehension level of young drivers. Also, as expected, local traffic signs were understood by more people than were nonlocal signs (Shinar et al., 2003).

On the basis of their findings, Shinar et al. (2003) suggested that signs that are consistent with ergonomic guidelines for display design are more likely to be understood than signs that do not comply with these guidelines. This hypothesis was based on a post hoc nonquantitative evaluation of the signs that were well understood and the signs that were not well understood.

There are five main ergonomic principles relevant to traffic signs design (Sanders & McCormick, 1993): (a) *spatial compatibility* – the physical arrangement in space, relative to the position of information and directions; (b) *conceptual compatibility* – the extent to which symbols and codes conform to people's associations; (c) *physical representation* – the similarity between the content of the sign and the reality it represents; (d) *familiarity* – the extent to which the driver is familiar with the sign from his or her driving experience; and (e) *standardization* – the extent to which the codes used for different dimensions, such as color and shape, are consistent for all signs. The standardization and compatibility principles may be the most significant issues when addressing the problem presented by Shinar et al. (2003), in which drivers who rent a car in a foreign country have no past experience with its unique signs and cannot understand the local language and signage conventions.

In general, most signs belong to one of three types: warning signs, regulatory signs, and guidance or information signs. Every one of these types should be distinct in its shape and color. Unfortunately, standards and regulations for traffic signs design vary across countries. For example, in Israel warning signs are designed as an equilateral triangle pointing up, with a red frame and a white background; most regulatory signs are round with a red frame and a white background; and most of the information signs are rectangular with a blue, green, or brown background (Israel Ministry of Transporation, 2002). In contrast, in the United States standards are very different: Most warning signs are typically diamond-shaped with a yellow background, regulatory signs are usually rectangular with a white background, and most guidance signs are rectangles with blue, green, or brown background (Institute of Transportation Engineers, 2003). However, what is probably the most important sign – the "stop" sign – has a distinct octagonal design with a red background in both countries (and most of Europe).

The goal of this study was to directly test the relationship between sign comprehension and the extent that signs comply with ergonomic principles for design, as was suggested but not tested by Shinar et al. (2003). In order to compare the two studies (Shinar et al., 2003, and the current study), we used the same set of signs and the same method to assess sign comprehension. In addition, the present study also evaluated each sign's compliance with three ergonomic principles: (a) compatibility – a combination of three principles (spatial compatibility, conceptual compatibility, and physical representation, all relating to how the sign is perceived by the driver), (b) familiarity, and (c) standardization.

METHOD

Three independent evaluations/experiments were conducted on the same set of traffic signs. In the first, we used undergraduate students to test the signs' comprehension level and to evaluate their compatibility, familiarity, and standardization level; in the second evaluation human factors and ergonomics experts assessed the compatibility of the same signs; and in the third evaluation we assessed the compliance of the signs with the standardization (based on the Israeli standards).

The separate and independent compatibility and standardization evaluations were conducted in order to make sure that these principles were correctly understood by the participants in the first experiment.

Participants

Participants in the first experiment were 23 male and 17 female industrial engineering and management undergraduate students from Ben-Gurion University of the Negev. Their average age was 28.8 years (SD = 2.4). All were licensed drivers, with 3 to 15 years of driving experience (average = 7.0, SD = 2.5). Thirteen participants reported driving less than 500 km/month (about 6000 km/year), 18 drove 500 to 1000 km/month, 5 drove 1100 to 1500 km/month, and 4 drove more than 1500 km/month.

The compatibility evaluation was made by 13 human factors and ergonomics professors and advanced graduate students from Ben-Gurion University of the Negev.

The standardization assessments were made by the authors, who have the combined experience of 35 years of teaching human factors and ergonomics.

Materials

The first experiment used a computer program written in MS Visual Basic. It was administered individually on PCs in a computer classroom. All computers were set to a resolution of 600 × 800, and all had 17-inch (43-cm) screens. A standard mouse and keyboard were used for responses.

Each participant was given a short demographic questionnaire, a sign comprehension questionnaire, and three evaluation questionnaires (detailed in the Experimental Design and Procedure subsection).

The demographic questionnaire contained questions on the driver's age, gender, driving license type, driving experience, and average monthly number of kilometers of driving. The sign comprehension test consisted of 30 color pictures of highway traffic signs used in the previous study by Shinar et al. (2003), presented one at a time. Figure 1 presents the sign images, and Table 1 provides the meaning of these signs. (Because of a technical problem, one of the 31 signs used by Shinar et al. [Sign 24, parking for public transport] was excluded from the analysis.)

This set of signs includes warning signs, regulatory signs, and information signs. Of the 30 signs, 15 were international signs that are common to all four countries participating in the Shinar et al. (2003) study (Canada, Finland, Israel, and Poland). The remaining 15 signs were unique to specific countries. Of the 30 signs, 20 are used in Israel and the other 10 signs are not used in Israel (see Figure 1).

Diamond-shaped and square-shaped signs were 7 to 10 cm across, triangular signs were 10 cm high, and circular signs were 10 cm in diameter.

In the compatibility evaluation, the experts were given a questionnaire containing the pictures and meanings of the 30 signs, and they were asked to rate each sign for its compliance with the compatibility principle (the questionnaire's content is detailed in the Experimental Design and Procedure subsection).

Experimental Design and Procedure

The first experiment included four parts: general instructions, anonymous demographic questionnaire, sign comprehension questionnaire, and three sign evaluation questionnaires according to each of the three ergonomic principles (physical and conceptual compatibility, familiarity, and standardization).

In the sign comprehension part, all participants were shown all 30 signs (see Figure 1 and Table 1). Each participant was presented with the signs in a different random order. Every screen in the comprehension test showed a picture of one sign accompanied with the question "What does this sign mean?" and a text box where the participants were asked to type, in their own words, the meaning of the sign. The decision to let the participants type the meaning in their own words rather than use multiple-choice scale was based on the desire to stay consistent with Shinar et al.'s (2003) procedure. This approach also has greater ecological validity in light of Dewar's (1994) comment that the degree of similarity of the distractors to the correct answer can influence sign comprehension, sometimes making it easier to recognize the correct meaning of a sign.

The next stage of the experiment was an evaluation questionnaire. The participants were presented with three questionnaires (in a random order), one for each ergonomic principle. They were asked to evaluate on a 1 to 10 scale the extent to which each of the 30 signs complied with the displayed principle. Each screen showed in a random order one of the signs, the sign meaning, the definition of the relevant ergonomic principle on which it was supposed to be rated, the question "Does this sign comply with the principle of…?" and an array of 10 buttons. Figure 2 displays an example of one screen.

The ergonomic principles were defined to the participants as follows:

- *Physical and conceptual compatibility* – the correspondence between the sign and the message it represents. For example: A plane symbol represents airport (association); an arrow pointing right

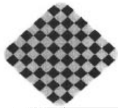
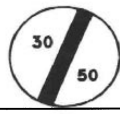
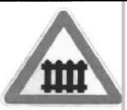
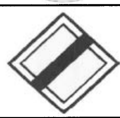
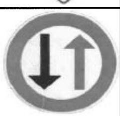
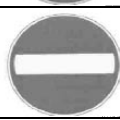
Sign No	Picture	Colours	International	Local	Sign No	Picture	Colours	International	Local	Sign No	Picture	Colours	International	Local
1		orange, black	no	no	11		red, white, black	yes	yes	21		orange, black	no	no
2		orange, black	no	no	12		black, orange	no	no	22		white, black	no	yes
3		blue, white	no	no	13		red, white, black	yes	yes	23		black, yellow, red	no	no
4		red, white, black, orange	no	no	14		red, white, black	yes	yes	25		red, white, black	yes	yes
5		red, white, black	no	yes	15		red, black, white	no	yes	26		yellow, white, black	no	yes
6		yellow, black	no	no	16		red, white, black	yes	yes	27		red, white, black	yes	yes
7		red, white, black	no	yes	17		red, white, black	yes	yes	28		red, white	yes	yes
8		dark blue, white	yes	yes	18		red, white, black	yes	yes	29		red, white, black	yes	yes
9		red, white, black	yes	yes	19		red, white, black	yes	yes	30		dark, blue, red	yes	yes
10		red, white, black	yes	yes	20		yellow, black	no	no	31		yellow, black	no	no

Figure 1. The 30 highway traffic signs used in the study.

represents right turn in the road (physical resemblance); a traffic light picture represents the presence of nearby traffic light. In these examples, the sign fully complies with this principle (Score 10).

- *Standardization* – consistency, homogenous representation of forms/colors/symbols/directions and so forth, in all traffic signs for presenting a similar message. For example: Using blue instruction signs in highways in contrast to green instruction signs in other roads complies with this principle (Score 10).
- *Familiarity* – the frequency of the sign in the road. For example: a "stop" sign is very frequent and familiar and therefore fully complies with this principle (Score 10).

The participant's task was to click one of the compliance score buttons and then click the "next" button. The experiment was paced by the participant and not limited in time.

TABLE 1: Signs and Their Meanings

Sign	Sign Meaning
1	Railroad crossing with lights
2	Truck crossing
3	Bus lane begins
4	No entry for vehicles carrying explosives
5	No entry for motorcycles/mopeds
6	Reverse turn (left then right)
7	Priority for oncoming traffic
8	Bicycle path
9	Road works
10	Bumps on road
11	Right curve
12	Termination of road
13	Railroad crossing ahead
14	Slippery road
15	Congestion
16	Road narrows
17	Pedestrian crossing ahead
18	Children crossing ahead
19	Steep hill ahead
20	Diagonal railroad crossing ahead
21	Truck entrance
22	End speed limit (for trucks, 30 km/hr; for cars, 50 km/hr)
23	End built-up area
25	No U-turn
26	End priority road
27	No left turn
28	No entry
29	No entry for pedestrians
30	No parking
31	Pavement ends

In the compatibility evaluation experiment, we presented the compatibility principle as a combination of three principles and defined each of these principles as follows: *spatial compatibility* – the physical arrangement in space, relative to the position of information and directions (i.e., the direction in which the road is turning is presented by an arrow's turn in the sign); *conceptual compatibility* – the extent to which symbols and codes fit the associations most people have for the concept (e.g., an airplane sign will present a nearby airport); and *physical representation* – the similarity between the content of the display and the object or situation it represents (e.g., a picture of people working implies road construction nearby).

The experts were asked to rate each of the 30 signs on a 0 to 3 scale, so that 0 meant the sign does not comply with any of the compatibility principles, 1 or 2 means the sign complies with one or two of the compatibility principles, and 3 means the sign fully complies with all the compatibility principles. These defined ratings were supposed to give the experts a common quantitative scale with which to evaluate the signs' compliance with the compatibility principle.

In the same way, the standardization evaluation was based on defined and clear definitions of the sign's shape, color, and coding. According to Israeli regulations (Israel Ministry of Transportation,

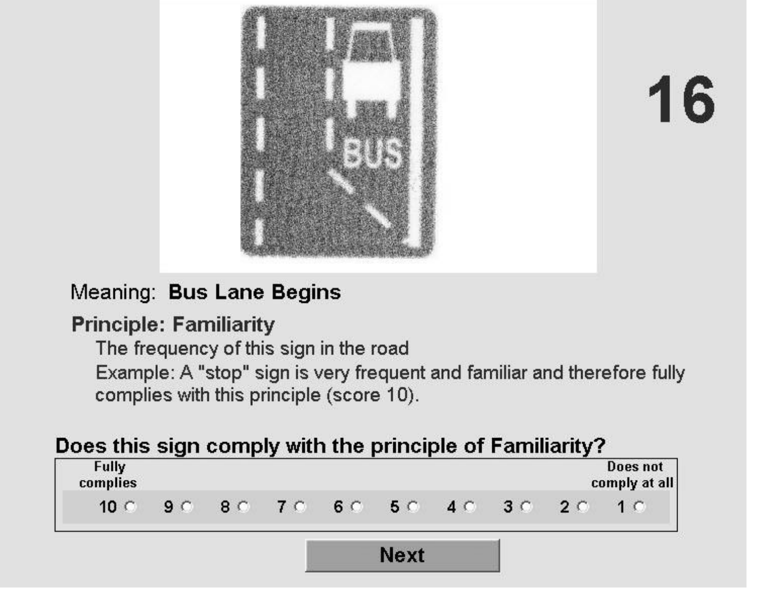


Figure 2. Evaluation screen presented to the participants in the experimental program.

2002), warning signs are designed as an equilateral triangle (shape) pointing up (code), with a red frame and white background (color); regulatory signs are round (shape) with blue background or with red frame and white background (color) – some also have a red diagonal line (code) to represent prohibition – and information signs have a rectangular shape and blue, green, or brown background (color).

The rating for each sign was on a 0 to 3 scale, with 0 meaning that "the sign does not comply with the standardization principle at all" and 3 meaning that "the sign fully complies with the standardization principle." For example, if the sign complied with one of the three components of the sign design (shape, color, or coding), it was scored 1. Information signs that do not have code distinction automatically got the code point if one of the other two components was present. Thus, the standardization scale for the information signs was 0, 2, or 3.

RESULTS

Differences in Sign Comprehension

The participants' responses in the comprehension questionnaire were coded, as in Shinar et al.'s (2003) study, into one of four categories of accuracy: correct and complete (coded as +2), partially correct (e.g., "no turn" instead of "no left turn" was coded as +1), incorrect (coded as 0), or opposite of the sign's true meaning (e.g., "priority for ongoing traffic" instead of "priority for oncoming traffic" was coded as –2).

Comparisons among the four comprehension levels of different signs based on percentage of responses in each defined category (correct and complete, partially correct, incorrect, or opposite of the sign's true meaning) are presented in Table 2. Comprehension varied greatly among the signs. Some of the signs were identified and understood (correct and complete response) by more than 90% of the participants (Signs 8, 9, 14, 17, 18, 25, 27, 28, and 29), whereas other signs were misunderstood (incorrect response or opposite of the true sign meaning response) by over 50% of the participants (Signs 4, 7, 12, 22, and 26). In addition, for four signs, 10% or more of the participants misinterpreted the sign to mean the opposite of its true meaning: Sign 5 (no entry for motorcycles, misinterpreted as "motorcycles permitted"), Sign 19 (steep hill ahead, misinterpreted as "downhill ahead"), Sign 20 (diagonal railroad crossing ahead, misinterpreted as "inactive railroad crossing"), and Sign 22 (end speed limit, misinterpreted as "begin speed limit"). Generally it was found that 56.42% of all responses (for all signs) were correct and complete (coded as +2).

The probability of sign comprehension correlated significantly with years of driving ($r = .394$, $p < .001$) but was not associated with the reported number of kilometers driven monthly, $F(3, 36) = 0.894$, $p = .453$.

Pearson correlation was used to compare results of the current study with the results obtained for the equivalent sample of drivers who participated in the Shinar et al. (2003) study (50 Israeli undergraduate students). Two correlations were conducted: The first was for percentage of fully correct responses (with a score of +2) for each sign and the second was for percentage of partially or fully correct identifications (i.e., scores of either +1 or +2). Results showed high and significant correlations for both comparisons: $r = .76$, $p < .001$, and $r = .85$, $p < .001$, respectively. In both studies Signs 8, 14, 17, 18, 25, 27, 28, and 29 were correct and fully understood by over 90% of the participants; Signs 4, 12, and 26 were not understood at all by more than 50% of the participants; and for Signs 5 and 22, the opposite meaning was understood by more than 10% of the participants (see Table 3).

The decision to use the percentage of fully correct responses (with a score of +2) as a measure for comprehension level was based on multiple data analyses that were conducted in the previous study (Shinar et al., 2003). These included analyses of the average rating scores (and that is why the "opposite of correct" answer was given a code of –2, and not –1 or zero), the percentage correct at either +1 or +2, and the percentage correct at +2 (the measure that was ultimately used). Interestingly all the analyses yielded similar patterns and effects.

Sign Comprehension and Compliance With Ergonomic Principles

Because there was a possibility that some participants (students and experts) would use different criteria for evaluating the signs, we screened outliers by correlating each participant's rating of each sign with the average rating based on the

TABLE 2: Percentage of Responses for Each Sign in the Four Categories

	Percentage of Responses			
Sign	Correct (+2)	Partial (+1)	Incorrect (0)	Opposite (–2)
1	2.5	57.5	40.0	0.0
2	27.5	25.0	45.0	2.5
3	67.5	25.0	7.5	0.0
4	10.0	25.0	63.0	2.5
5	75.0	0.0	0.0	25.0
6	20.0	67.5	13.0	0.0
7	40.0	0.0	55.0	5.0
8	95.0	2.5	2.5	0.0
9	100.0	0.0	0.0	0.0
10	20.0	70.0	10.0	0.0
11	72.5	22.5	0.0	5.0
12	0.0	2.5	95.0	2.5
13	72.5	5.0	23.0	0.0
14	90.0	0.0	10.0	0.0
15	72.5	5.0	23.0	0.0
16	87.5	7.5	5.0	0.0
17	95.0	2.5	0.0	2.5
18	95.0	5.0	0.0	0.0
19	45.0	42.5	2.5	10.0
20	5.0	52.5	2.5	40.0
21	37.5	55.0	7.5	0.0
22	12.5	20.0	45.0	23.0
23	42.5	25.0	25.0	7.5
25	100.0	0.0	0.0	0.0
26	0.0	5.0	95.0	0.0
27	95.0	2.5	0.0	2.5
28	97.5	0.0	2.5	0.0
29	95.0	5.0	0.0	0.0
30	80.0	5.0	15.0	0.0
31	40.0	47.5	13.0	0.0

Note: Total of each row = 100%.

ratings of all other participants. Participants whose answers were grossly inconsistent with those of the majority ($r < .5$) were excluded from the analysis. This filtering process resulted in excluding 2 of the 40 students and 1 expert from the following statistical analysis.

Table 4 presents the mean evaluations, after transformation to standard Z scores, for each sign on each of the three ergonomic principles and in all three experimental evaluations. As can be seen in Table 4, some of the signs received high scores (the top 20% of the scores) on all three ergonomic

TABLE 3: Comparisons of Comprehension Levels for the Different Signs Between the Current Study and Shinar et al. (2003)

	Current Study	Shinar et al. (2003)
Signs that were correct and fully understood by more than 90% of participants	8, 9, 14, 17, 18, 25, 27, 28, 29	8, 11, 14, 17, 18, 19, 25, 27, 28, 29
Signs that were not understood at all by more than 50% of participants	4, 7, 12, 26	3, 4, 12, 15, 20, 22, 26
Signs for which the opposite meaning was understood by more than 10% of participants	5, 19, 20, 22	2, 5, 7, 22

TABLE 4: Standardized Evaluation Scores Made by Undergraduate Students and Experts for Each Sign on the Three Ergonomic Principles

	Students			Experts	
Sign	Compatibility	Familiarity	Standardization	Compatibility	Standardization
1	–1.47	–1.27	–1.37	–0.99	–1.40
2	–0.29	–0.79	–0.88	0.40	–1.40
3	0.30	–0.52	–0.42	0.89	0.85
4	–0.70	–1.48	–0.34	–0.99	0.10
5	0.52	–0.05	0.52	0.60	0.10
6	0.33	–0.28	–0.51	0.20	–1.40
7	–0.44	0.27	0.23	–0.19	0.85
8	0.90	0.33	0.65	0.70	0.85
9	1.03	0.91	0.94	0.99	0.85
10	–0.35	0.27	0.36	–1.09	0.85
11	0.80	1.16	0.89	0.99	0.85
12	–2.47	–1.62	–2.41	–1.98	–1.40
13	–0.05	0.24	0.35	–0.19	0.85
14	0.72	0.72	0.83	0.50	0.85
15	0.35	0.12	0.29	0.50	0.10
16	0.76	0.68	0.86	0.60	0.85
17	1.04	1.18	1.03	1.29	0.85
18	0.99	1.15	0.99	1.09	0.85
19	0.85	–0.21	0.83	0.70	0.85
20	–0.38	–1.24	–1.16	–0.39	–1.40
21	–0.53	–1.11	–1.07	–0.59	–1.40
22	–0.89	–0.51	–0.57	–1.28	0.10
23	0.19	–0.84	–0.57	–0.89	–1.40
25	1.08	1.43	1.06	1.09	0.85
26	–2.37	–1.59	–2.34	–2.07	–1.40
27	1.09	1.30	1.05	1.09	0.85
28	–0.73	1.49	0.58	–0.49	–0.65
29	1.01	0.52	1.00	1.09	0.85
30	–1.43	1.04	0.12	–1.68	0.10
31	0.15	–1.32	–0.91	0.10	–1.40

principles, both by students and experts (Signs 9, 17, 18, 25, and 27), whereas other signs got low scores (the lowest 20% of the scores) on all three principles (Signs 12 and 26). A few signs were given a high score on one principle and a low score on another. For example, Signs 28 (no entry) and 30 (no parking) were given a high score in familiarity but a low score in compatibility (by both students and experts); Sign 31 (pavement ends) received a relatively high score on compatibility but low scores on both familiarity (this is a nonlocal sign) and standardization; and Sign 19 (steep hill ahead) was given high scores in compatibility and standardization but low scores on familiarity (this is a local sign but is not very common in Israel).

Spearman rho nonparametric correlations revealed very high and significant relationships between the average ratings of the students for each sign and the experts' average ratings for that sign. This was true for both the compatibility ratings ($r = .94$, $p < .001$) and for the standardization ratings ($r = .84$, $p < .001$). Hence, it seems that the participants in the first experiment (i.e., the undergraduate students) with the aid of the specific definitions for compatibility and standardization evaluated the signs correctly, and therefore all further analyses will be based on the results of the first experiment only.

We tested the relationship between sign comprehension level, based on percentage of fully correct responses (+2) for each sign, and the extent to which the signs comply with each of the ergonomic principles using Spearman nonparametric correlations. Figure 3 presents in three separate graphs the relationships between comprehension

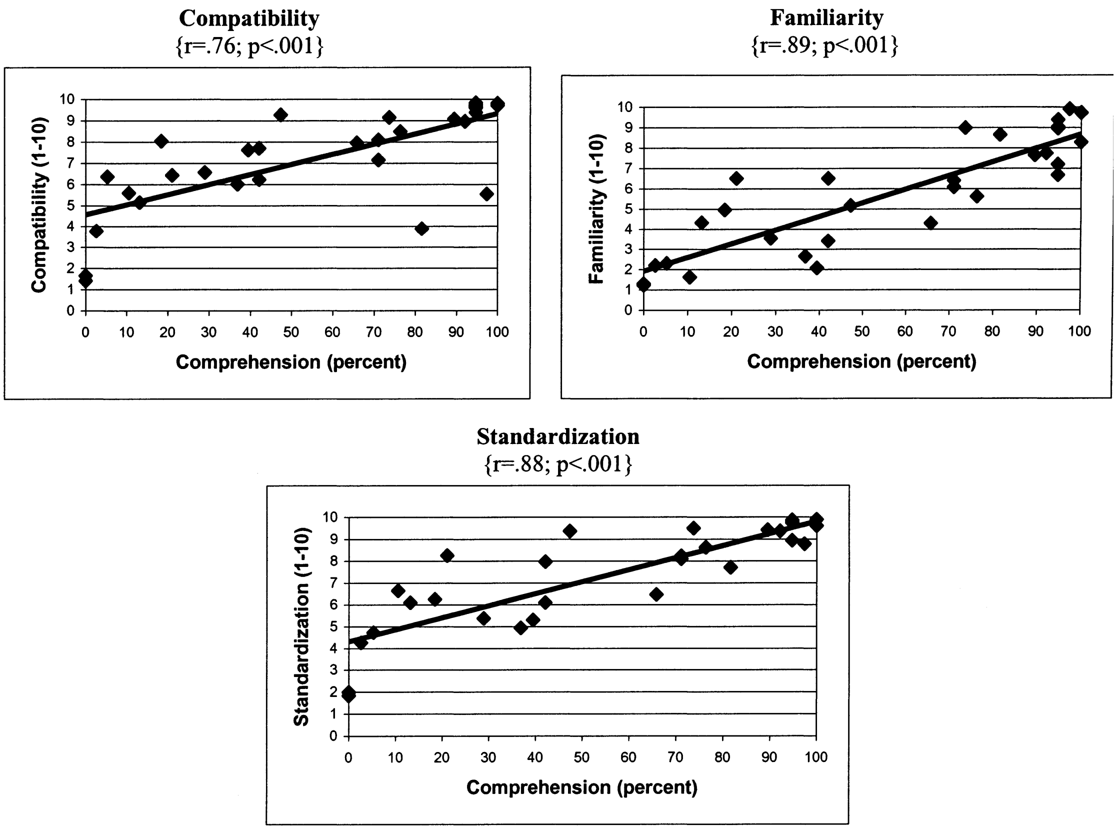


Figure 3. The relationships between comprehension level (percentage of correct responses) and the three ergonomic principles: compatibility, familiarity, and standardization (on a 1–10 scale).

level and the ergonomic principles of compatibility, familiarity, and standardization. As can be seen from the three charts, there were high and significant correlations between percentage of fully correct responses and the extent to which the sign complies with the compatibility principle ($r = .76$, $p < .001$), the extent to which the sign was familiar ($r = .89$, $p < .001$), and the extent to which it was standard ($r = .88$, $p < .001$). The correlations among the three ergonomic principles were also highly significant (all with $p < .001$) and quite high: $r = .64$ between familiarity and compatibility, $r = .88$ between familiarity and standardization, and $r = .85$ between standardization and compatibility.

Linear regression was used, and multiple correlations were computed, to test the joint effects of all three ergonomic principles on correct comprehension probability (coded as +2). The regression was highly significant, $F(3, 26) = 38.243$, $p < .001$, with a very high multiple correlation ($r = .904$, $R^2 = .815$). Table 5 presents the regression's β coefficients and their significance. According to this analysis, familiarity contributed the most to comprehension, followed by compatibility (the partial effect of which, after familiarity was taken into account, was only marginally significant). The partial effect of standardization was negligible and statistically nonsignificant, beyond the effects of familiarity and compatibility.

However, there is a multiple collinearity problem in this model. Because the multiple correlations between all three principles and the level of comprehension was not much higher than the correlations between each principle and comprehension, and because the three factors also correlated among themselves, it is hard to assess the separate contribution of each factor to comprehension. One reason for this is that in most signs the three principles are combined. In a stepwise regression procedure, familiarity alone yielded $R^2 = .76$, and the addition of compatibility significantly increased

TABLE 5: Regression β Coefficient Analysis Comparing Effects of the Three Ergonomic Principles[a] on Comprehension Probability

	Coefficients[b]				
	Unstandardized		Standardized		
Model	*B*	*SE*	β	*t*	Sig.
Constant	–26.806	11.344	—	–2.363	.026
Avg. compatibility	4.790	2.599	.315	1.843	.077
Avg. familiarity	9.104	2.629	.706	3.463	.002
Avg. standardization	–0.510	4.478	–.033	–0.114	.910

[a]Compatibility, familiarity and standardization. [b]Dependent variable: percentage of correct and complete responses (coded as +2).

the correlation to $R^2 = .815$. The addition of standardization as a third variable did not yield a further significant increase in the correlation. To directly assess the relative contribution of the three ergonomic principles, a more theoretical study must be conducted with artificial abstract symbols, in which the three principles would not be confounded as they are in real-life signs. Still, some evidence for the importance of the three principles can be seen in the few cases in which all principles are violated (e.g., Sign 12, termination of road, and Sign 26, end priority road), for which comprehension was typically very poor, as well as in the few cases in which all principles are fully met (e.g., Sign 9, road works, and Sign 11, right curve), for which comprehension was very high. Thus all three principles are important, even though the exact and unique contribution of each of them is hard to determine.

Another way to consider the effects of all three ergonomic principles on comprehension involved developing for each sign an "ergonomic quality" score, which was essentially the unweighted mean score on all three principles (compatibility, familiarity and standardization). The correlation between the ergonomic quality and the signs' comprehension level (percentage of fully correct responses) was $r = .91$ ($p < .001$), which, again, is not significantly greater than the correlation between comprehension and familiarity alone.

Finally, given the strong effects of familiarity, we also looked at the differences in ratings between local and nonlocal signs on each of the ergonomic principles. Figure 4 displays average ratings on each of the ergonomic principles for local and nonlocal signs. No significant difference in the average compatibility rating was found between signs that are used in Israel and signs that are not used in Israel, $t(1, 28) = 1.99$, $p = .057$. However, local signs, as expected, were rated as significantly more familiar, $t(1, 28) = 6.06$, $p < .001$, and also as more standardized, $t(1, 28) = 5.10$, $p < .001$.

That local signs were perceived as more familiar or more frequent than nonlocal signs was expected. However, among the local signs there were also differences in familiarity level, and the more familiar signs were also more likely to be comprehended correctly by more people. Figure 5 presents the relationship between familiarity and comprehension level for the 20 local signs used in this study. Even within group, the graph shows a strong linear relationship between the two factors, with $r = .82$, $p < .001$.

DISCUSSION

The goal of this study was to directly test Shinar et al.'s (2003) suggestion that there is a relationship between highway traffic signs comprehension or understanding probability and the extent to which the sign complies with three ergonomic principles: sign-content compatibility, familiarity, and standardization. The main question of this study was whether traffic signs that comply with ergonomic principles are more comprehensible than signs that are not ergonomically designed.

Comparisons between comprehension levels of signs in the current study and those obtained in Shinar et al.'s (2003) study revealed high and significant correlations between the results of the two studies. Both studies found great variability in comprehension level of different traffic signs and a consistency in the level of comprehension of

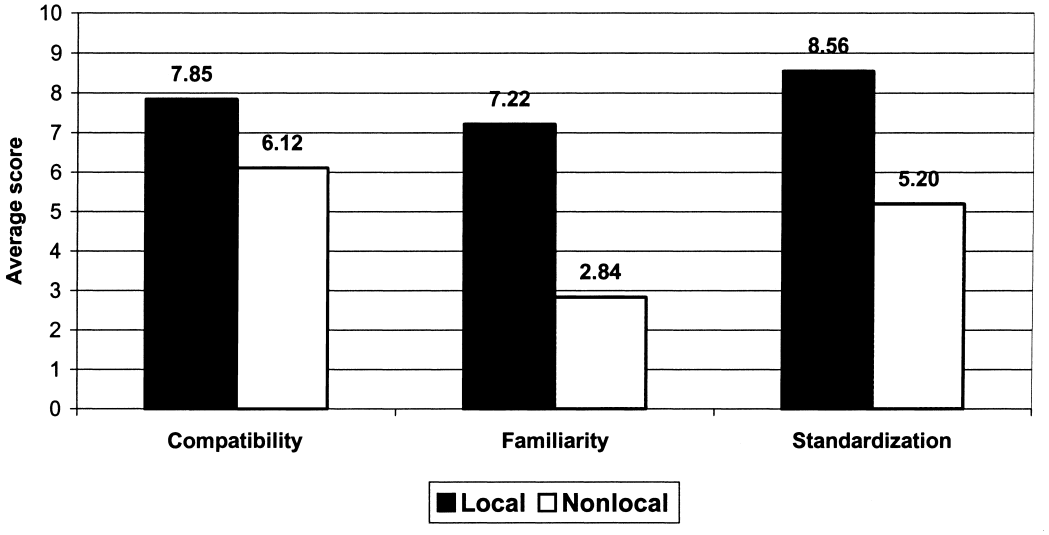


Figure 4. Average ratings on each of the ergonomic principles for local and nonlocal signs.

different signs across the two studies. Some signs were correct and fully understood by most of the participants, whereas others were not understood at all or were interpreted as having the opposite meaning. As can be expected, all fully comprehended signs in both studies were local signs, suggesting that the familiarity factor has a large impact on comprehension. These findings support previous cross-cultural studies (i.e., Al-Madani & Al-Janahi, 2002; Al-Yousifi, 1999; Shinar et al., 2003) that found cultural differences in comprehension of the same signs. These studies also found that signs with high comprehension levels in one culture may not be understood at all in another culture.

In general, both the current study and the one by Shinar et al. (2003) found that the same signs were understood or misunderstood by the drivers. Another similarity was in signs that the participants understood as having the opposite of their true meaning. Two signs – Sign 5 (no entry for motorcycles) and Sign 22 (end speed limit) – were understood as having the opposite meaning by more than 10% of the participants in both studies. These misunderstandings can have dangerous and even deadly outcomes on the road.

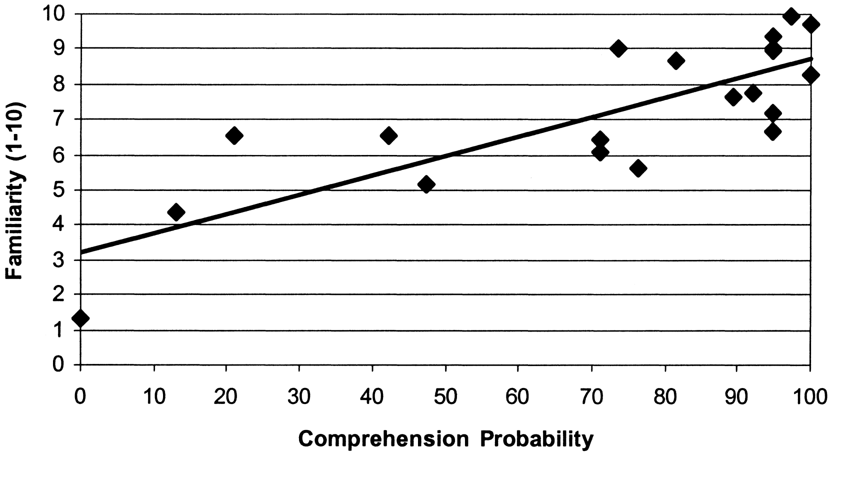


Figure 5. Relationship between comprehension probability and familiarity level for the 20 local signs.

Results of this study revealed high and significant correlations between probability of sign comprehension and the extent to which the sign complies with every one of three ergonomic principles: compatibility, familiarity, and standardization. The compliance of signs with the compatibility and standardization principles was evaluated independently by undergraduate students who had had no prior encounter with these ergonomic principles and by human factors and ergonomics professors and graduate students. Both evaluations yielded the same results. In addition, we found high and significant correlations between the probability of sign comprehension and the sign's "ergonomics" (i.e., the extent to which the sign complies with all three ergonomic principles).

The compatibility principle is a combination of three principles – spatial compatibility, conceptual compatibility, and physical representation – and deals with the perception of the sign by the driver. A symbol or sign with a high compatibility level will easily reflect the message that it is supposed to represent to the driver. The high and significant correlation found between compatibility level and comprehension probability suggests that if the symbol presented on a traffic sign reflects the driver's associations or has a physical resemblance to reality, it can positively influence the comprehension of the sign by the driver. For example, Sign 31 (pavement ends), even though it is not a local traffic sign, was fully or partially understood by over 87% of the participants. Therefore it was given a relatively high average rating in compatibility but a low average rating in familiarity.

Creating an international standard in sign compatibility might be difficult because cultural differences among drivers might influence their associations. For example, the picture of a fence presented in Sign 13 (railroad crossing ahead) might not be associated with a railroad, because in some countries there are no similar fences near railroad tracks. In order to minimize these cultural differences, sign symbols must be common to the entire motorized world – for instance, pictures of humans (Signs 17 and 18), or common modes of transportation such as bicycles (Sign 8), motorcycles (Sign 5), and trucks (Sign 2). The contribution of compatibility and standardization was evident in the comprehension of some of the nonlocal signs, such as Sign 3 (bus lane begins). This sign was fully understood by 67.5% of the participants (and another 25% partially understood it). Finally, compatibility implies that the sign content should be related to reality, and that should not have cultural limitations. Signs 12 (termination of road) and 26 (end priority road), for instance, do not create any associations to a driver (in any culture) who is not already familiar with them. Thus these symbols do not reflect reality, and, as might have been expected, most of the drivers in our research did not understand their meaning (despite the fact that Sign 26 is a local sign).

The standardization principle strongly relates to the problem raised by Shinar et al. (2003) regarding driving in a foreign country. Standardization was based on shape, color, and coding used in traffic sign design in order to keep them consistent and homogenous. Currently, there is no international standard for traffic signs design. A comparison between Israeli and American standards shows some similarities in shape and color of information signs and regulatory signs, but in the signs that are most important for safety – warning signs – there is no consistency: The Israeli warning signs are designed as a equilateral triangle pointing up, with a red frame and white background, whereas most of the American warning signs are diamond-shaped and have a yellow background.

In addition, there are often inconsistencies in traffic signs within a specific country. For example, Israeli regulatory signs, which prohibit certain maneuvers, are all round with a red frame and white background. However, in some of them the prohibition is noted by a red diagonal line over the prohibited maneuver and in others by simply showing the relevant object without a line. The resulting confusion was illustrated in our study when 25% of the participants ascribed to Sign 5 (no entry for motorcycles) the opposite meaning, "motorcycles allowed." This mistake might be deadly and is reinforced by other (more compatible) prohibition signs that have a diagonal line to indicate the prohibition (e.g., Sign 25, no U-turn, and Sign 29, no entry for pedestrians). Therefore, local standards that are not applied consistently create ambiguity and can lead to unsafe behaviors.

The familiarity principle deals with the frequency that a driver encounters different traffic signs. The frequency level of a sign varies from country to country, and there is no international standard regarding frequency of use of specific signs.

The results showed a strong and positive relationship between the level of comprehension and the perceived familiarity. From these results, it can be assumed that comprehension probability is somehow associated with a learning process. Even though the unique contribution of familiarity is hard to determine, it can be assumed that when a sign is more familiar or frequent, drivers have more opportunities to learn its meaning and retain that information in memory. It then becomes more comprehensible, independent of its compliance with other ergonomic principles. A good example is the no-parking sign (Sign 30), which was fully understood by 80% of the participants. Another example is the end built-up area sign (Sign 23), which was fully understood by 42.5% and partially understood by another 25%. Another finding that supports the learning explanation is the high and significant correlation found between sign comprehension and years of driving experience.

Despite the importance of familiarity, it should not be relied on when designing traffic signs, given that familiar and frequent signs in one country can be rare or even nonexistent in other countries. Thus, a tourist driving in a foreign country may not recognize some signs that are very common locally. Even in one's own country, nonstandard low-compatibility signs may require a significant number of exposures to be comprehended. Therefore, sign designers should make sure that the signs they are designing comply with the compatibility and standardization principles and that they will be correctly understood the first time they are viewed.

One methodological issue could have affected the validity of the present results: whether or not the students participating in the main experiment of this study fully understood the meaning of each of the ergonomic principles presented to them during the experiment. The participants were industrial engineering and management undergraduate students who had not yet had any courses in ergonomics, and therefore they encountered the definitions of these ergonomic principles for the first time during the experiment. However, in order to avoid this problem, we conducted separate evaluations of the signs' compatibility and standardization according to human factors and ergonomics professors, advanced graduate students, and the researchers of this study. Comparisons of the evaluations by the undergraduate students and those by the human factors experts showed that the students correctly understood the ergonomic principles presented to them, and therefore their responses are valid.

Conclusions and Implications

Results of this study demonstrated a strong relationship between a sign's compliance with all three ergonomic principles – compatibility, familiarity, and standardization – and its comprehension probability. Significant and linear correlations were found for these three parameters. Even though the combined influence of the ergonomic guidelines for design on comprehension level was not proven to be significantly higher than that of the most significant factor (familiarity), significant correlations were found between comprehension level and each of the other two ergonomic design principles (compatibility and standardization). This means that the three concepts, though they may be conceptually different, are in practice confounded to a large extent.

It is obvious that traffic sign designers cannot influence the extent to which a sign is familiar to the driver and that a newly designed sign would certainly be unfamiliar to the driver. However, designing new signs according to the compatibility guidelines (i.e., complying with spatial compatibility, conceptual compatibility, and physical representation) and the standardization guidelines (i.e., complying with standard shape, color, and coding) presented in this study will no doubt influence the understandability of these new signs.

Because ergonomically designed traffic signs – those that comply with basic ergonomic rules for design – are more understandable, the main conclusion of this research is that designing traffic signs according to ergonomic guidelines will improve sign comprehension and understanding for both local and nonlocal drivers. We can also conclude that when ergonomic principles such as compatibility and standardization are not complied with, the familiarity factor can help in the sign comprehension. It is obvious that understandable signs might save lives.

Another conclusion relates to the international standard issue. Cross-cultural studies have found that specific signs that are fully understood by the majority of the drivers in one country may not be understood at all by drivers from another country. These cultural differences can be attributed, as implied by the results of this study, to different sign design standards and conventions in each culture. Hence, an obvious conclusion is that creating uniform international standards for signage, and making these standards consistent with ergonomic principles of good design, will minimize cultural differences and will help to improve safety in all countries.

Findings of the current study are important for designers of road traffic signs, especially because they have international implications for good traffic sign design. This research proved that to improve sign comprehension probability, one must make sure that the signage system complies with at least one of the ergonomic guidelines for good design examined here: sign-content compatibility, standardization, and familiarity.

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