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Is three the magic number? The role of ergonomic principles in cross country comprehension of road traffic signs

Samantha Jamson (corresponding author)

Institute for Transport Studies, University of Leeds, Leeds, United Kingdom

Tel: +44 (0)113 3436606

Email: S.L.Jamson@its.leeds.ac.uk

Marco Mrozek

Institute for Transport Studies, University of Leeds, Leeds, United Kingdom

Tel: +44 (0)113 3436606

Email: marco.mrozek@gmail.com

ABSTRACT

Road sign comprehension plays an important part in road safety management, particularly for those drivers who are travelling in an unfamiliar country. Previous research has established that comprehension can be improved if signs are designed to adhere to ergonomic principles. However, it may be difficult for sign designers to incorporate all the principles into a single sign and may thus have to make a judgement as to the most effective ones. This study surveyed drivers in three countries to ascertain their understanding of a range of road signs, each of which conformed in varying degrees and combinations to the ergonomic principles. We found that using three of the principles was the most effective and that the most important one was that relating to standardisation; the colours and shapes used were key to comprehension. Other concepts which related to physical and spatial characteristics were less important, whilst conceptual compatibility did not aid comprehension at all.

Practitioner Summary: This study explores how road sign comprehension can be improved using ergonomic principles, with particular reference to cross-border drivers. It was found that comprehension can be improved significantly if standardisation is adhered to and if at least three principles are used.

Keywords: road signs, comprehension, cross-border, safety

Introduction

Since 2004, thirteen countries with more than 110 million inhabitants have joined the EU and travel restrictions between EU and non-EU countries have become increasingly loose (MFA, 2010). Rising European integration leads to increases in migration and hence more cross-border traffic movements. This is particularly so during holiday time when a concomitant rise in traffic offences also occurs. For example, in France (typically a transit country), 25% of all traffic offences are committed by non-domestic drivers increasing to 40-50% during the summer-peak season (European Commission, 2013).

In response, the EU adopted a Cross-Border Enforcement Directive in 2015. Its aim was to improve road safety by offering a tool for enforcement authorities in the Member State where an offence is committed, to pursue the offending driver of a vehicle registered in a different EU Member State. For example, if a car which is registered in Italy is recorded as having violated a red traffic light in Spain, this information is conveyed to the national contact point in Spain who can send a request to Italy for the registered address. The Spanish contact point can then choose to follow up the offence by informing the holder of the Italian registration certificate of the offence committed and its legal consequences under Spanish law. The Directive refers specifically to eight road safety related offences including speed and red-light violations, non-use of seat-belts and motorcycle helmets, driving under the influence of drink or drugs and illegal mobile phone use while driving.

It is hoped that drivers become motivated to take responsibility for learning the rules of the road on which they are travelling. One further inclusion in the Directive is the offence of using a forbidden lane (such as an emergency lane, a lane reserved for public transport, or a lane closed for road works). Conveying these forbidden acts to a road user is more likely to rely on road signage due to their specific geographic nature. This then poses the question: given that road signs are not fully harmonised across EU member states, how likely is it that road users fully comprehend all the nuances of the range of signs present in a country in which they do not reside?

As a brief background to road sign harmonisation, in 1909 the International Road Group defined traffic signs which related to five hazards: uneven roads, bends, railway crossings, intersections and road barriers (Rynowiecki, 2004). In 1926, the triangular form currently used for warning signs was defined. Then, in 1931 regulatory and mandatory signs were defined, including their colours and shapes which have remained unchanged until now. After World War II, the UN took responsibility for traffic sign harmonisation

and the Geneva Protocol on Traffic Signs and Signals defined 24 road traffic signs (World Bank, 1949). The Vienna Convention on Road Signs and Signals from 1968 included 41 traffic signs integrated in a European and American system which was ratified by 56 countries (Lay, 2004). However, since 1968, individual countries have introduced or abolished particular signs or pictograms to meet their own needs. Therefore the variety of traffic signs particular to, or unknown in, a country rises constantly. Despite efforts in harmonisation, different systems remain in Europe where road sign design incorporates the use of various sign shapes and colours to differentiate between regulatory, warning, regulatory, mandatory, information and direction signs (Shinar et al., 2003). Examples of these differences include:

- Warning signs which indicate hazards are represented by a red triangle with a white background in Germany, France and UK and a yellow background in Poland and Greece.

- While most countries use blue signage on motorways, Italy, Denmark and Sweden use green signs.

Thus, for more than a century, traffic signs have been one of the most important tools for road traffic management. They raise drivers' attention to particular hazards, convey driving restrictions and obligations and help with route-finding. Numerous studies (e.g. Charlton, 2006) have shown that when signs are poorly comprehended, drivers' ability to remember them and provoke the appropriate behavioural decreases. Elvik (1999) characterised the relationship between road signs and their impact on safety, Figure 1. He posits that the physical characteristics of sign conspicuity and visibility are precursors to the readability of a sign, such that those which are poorly lit or positioned will have low readability. Driver-centric issues such as motivation and understanding relate to sign design and affect comprehension – and ultimately compliance.

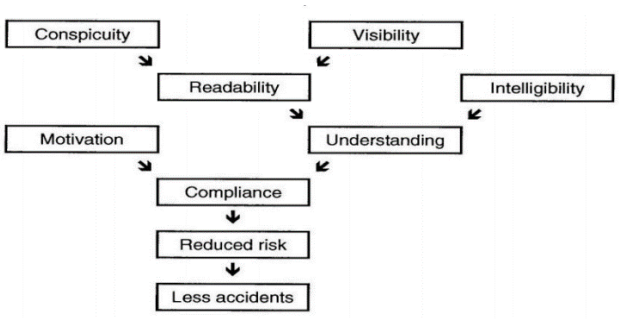

Figure 1: Relationship between traffic sign characteristics and road safety (Elvik, 1999).

A conspicuous object is one that 'attracts attention' (Engel, 1971) and a variety of methodologies have been employed to measure the concept such as eye movement studies (Mourant and Rockwell, 1972) and verbal reports (Cole and Hughes, 1984). Cole and Hughes (1984) defined two types of conspicuity – attention conspicuity and search conspicuity. The former refers to the ability of an object to attract attention when it is unexpected, whilst the latter relates to active search on behalf of the operator. However, a conspicuous sign will not be attended to if it is not physically visible. Characteristics of the sign itself (size and placement for example) and the surrounding environment (lighting and natural masking elements such as vegetation) are defined in regulatory manuals (e.g. Department for Transport, 2008). Signs that are intended to be read from a moving vehicle have to be of sufficient size to enable drivers to read them and assimilate the information in time. Their size is therefore dependent on the prevailing traffic speed and usually based on the 85th percentile approach speed. Minimum clear visibility distances inform the regulations, whereby drivers should have an unobstructed view of traffic signs. The higher the prevailing traffic speeds, the greater this distance needs to be, measured from the centre of the most disadvantaged driving lane.

As well as being conspicuous and visible, a sign's message must be readily understandable and drivers should know how to respond to it; poor comprehension can result in errors or delays leading to safety issues (Swanson et al., 1997). Ben-Bassat and Shinar (2015) highlighted this issue in their study – drivers who completely mis-understood a sign (i.e. reported the exact opposite meaning) did so with faster reaction times compared to slight errors. The authors describe these drivers as being "wrong – but sure".

Comprehension is regarded as the most important design factor for traffic signs; other criteria such as conspicuity, reaction time and legibility distance are of less importance (Dewar, 1988). Most European traffic signs are pictorial as they are superior to text-based signs in terms of conspicuity, legibility and comprehension; Edworthy and Adams (1996) summarise the main advantages of pictorial over text-based signs as being recognised more quickly, more accurately and from a longer distance. Furthermore, pictograms can be recognised by drivers who cannot speak or read the domestic language and are also less vulnerable to the effects of degradation (rust, mud and fading). Combining text with symbols is a useful alternative, as additional text allows unfamiliar drivers to learn symbols, without lengthening comprehension time for drivers familiar with the symbol (Shinar and Vogelzang, 2013). However, even when symbolic representation is used, comprehension can be low; Al-Madani and Al-Janahi (2002) for example found that

drivers understood only 58% of the signs presented to them and Dewar et al. (1994) reported understanding as low as only 40%in their study. Shinar et al. (2003) reported large differences in comprehension of individual traffic signs whereby one sign would be widely understood whereas another very little (as opposed to there being individuals who are particularly good or poor at sign comprehension).

Shinar et al. (2003) conducted a sign comprehension survey involving drivers from Israel, Canada, Poland and Finland to identify underlying factors that affect comprehension levels. They found that signs were comprehended best when they were consistent with the general ergonomics guidelines of:

(1) spatial compatibility – spatial arrangements in the real environment are relative to the position and direction shown on signs (typically stylised arrows e.g. 'right-curve').

(2) conceptual compatibility – symbols and colours concur with conceptual associations such as several buildings to indicate the start of a built-up area.

(3) physical compatibility – a symbol which depicts the real hazard e.g. disobeying the tram-sign results in a collision with the tram.

(4) familiarity – a traffic sign has no intrinsic meaning and is known to the driver only via training or frequent exposure.

(5) standardisation – the same colours and shapes are used for instruction, warning and information signs.

Shinar et al. (2003) and Ben-Bassat and Shinar (2006) argue that well comprehended traffic signs typically encompass several of these ergonomic principles and when they exist in singularity (e.g. familiarity) are not sufficient unless accompanied by other principles e.g. spatial or conceptual compatibility or training if the symbol is too abstract. However, it is not clear from their research which is the most important principle and the relative effects of omitting each of the individual principles. It would be virtually impossible for sign designers to include all five principles, but knowing which minimally to include, to ensure maximum comprehension, could be a useful guideline.

This study therefore focuses not only on quantifying the benefits of sign harmonisation but also the extent to which this harmonisation should hold true. For example, are small departures from the ergonomic principles acceptable? Are some principles more crucial to comprehension than others? To achieve this, a survey was carried out in three countries using a selection of signs, chosen for their conformity to the

ergonomic principles as outlined above. The countries chosen were Germany, Poland and the United Kingdom due to reported rises in non-domestic vehicles entering them:

- Between 1991 and 2004 the number of foreign cars entering Germany doubled from 11 to 21 million per year (Albrecht, 2007).
- Vehicles registered in Poland have the highest share among all foreign vehicles within Germany (24%) and the UK (35%), (SPARKS, 2007 and Lensing, 2010).
- In 2003, the number of cars and HGV's entering the UK was almost 3 times higher compared to 10 years before (Department for Transport, 2003).

Methodology

Various methodologies have been used to evaluate traffic sign comprehension. The roadblock paradigm involves stopping cars and interviewing drivers about the road signs they just passed (e.g. Johansson & Backlund, 1970; Milosevic & Gajic, 1986). Several of these studies have demonstrated that drivers have poor recall of road signs, thus as well as the inherent problem of memory decay in the roadblock paradigm (Fisher, 1992), research suggests that using a paradigm which relies on the conscious recall of road sign information may not be suitable. For example, a number of studies have noted that drivers may modify their driving behaviour in response to a road sign (such as a decrease in speed) without being able to consciously recall doing so (e.g. Häkkinen, 1965; Summala & Hietamäki, 1984). Field studies that use direct measures of performance (Lajunen et al. 1996; Jamson et al., 2005) can be augmented with eye movement recording (Costa et al. 2014) to provide further insight into the relationship between visual attention and behavioural response.

This study evaluated the comprehension of traffic signs by asking participants to write down the meaning of the traffic sign. This method does suffer from ecological validity as a correct response (e.g. braking, turning etc.) does not directly result from being able to name a sign (Castro et al., 2004). However, this method was chosen as the study was focussed on comprehension, rather than resulting action (which might be non-existent in the case of a warning sign). This method is more time-consuming, than for example a multiple-choice questionnaire, but it was felt important not to provide hints, as this is not the case in real driving. Presenting road signs out of context (i.e. in isolation as opposed to being embedded in a road scene has been found not to worsen comprehension (Ben-Bassat and Shinar, 2015). Signs were chosen for inclusion in the study on the basis that they related to either the manoeuvring or control level of driving (Michon, 1985) and had safety relevance (i.e. not information signs), Table 1.

Table 1: Traffic signs included in the study

	SIGN	MEANING	ORIGIN		SIGN	MEANING	ORIGIN
1		Right-curve ahead	Norway	17		Unguarded level crossing ahead	Ireland
2		Road works ahead	Romania	18		Accident hot spot	Bulgaria
3		Caution, children	Slovakia	19		End of road pavement	Belarus
4		Motorway ahead	Sweden	20		Fog	Czech Republic
5		National speed limit applies	UK	21		Road block	Hungary
6		Pedestrian crossing	France	22		Built-up-area	Denmark
7		Cross-over	UK	23		Dangerous Curves	Kosovo
8		Level crossing	Germany	24		Stop-Wrong way	Norway
9		Priority to oncoming vehicles	Poland	25		Wrong-way driver	Austria
10		Go straight or right	Greece	26		U-Turn mandatory	Austria
11		Elderly people	UK	27		Reduced visibility because of snow etc.	Nether-lands
12		No right turn	France	28		Accident hot spot	Czech Republic
13		Two-way traffic ahead	UK	29		No entry	Ireland
14		Lane grooves	Poland	30		Maximum curve speed	Denmark
15		Advisory speed	Germany	31		Priority road	France
16		Intersection ahead	Poland				

The traffic signs were scored for their adherence to the ergonomic principles of physical, spatial and conceptual compatibility. Each of the signs was independently evaluated against the criteria by raters. The raters collaboratively scored a number of signs (not included in the survey). This qualitative process allowed for discussion of the methodology to be used and clarification of the criteria. Then each sign included in the survey was independently assessed against the ergonomic principles. The scores from the two assessors were compared. Where there was disagreement which could not be resolved, the sign was omitted from the database of signs. Thus the signs included demonstrated 100% inter-rater reliability.

The traffic signs were additionally defined as being present in none, one, two or all three of the participating countries. This allowed the assessment of the effect of standardisation. Familiarity was not assessed as this concept reflects an individual driver's intrinsic exposure to that sign – something that could not be measured objectively. On completion of the scoring, some traffic signs adhered to one principle (e.g. Familiarity for 'Accident hot spot' and 'Advisory speed'), whereas others adhered to several (e.g. 'Road works', 'Children' etc.). This is visualised in Figure 2.

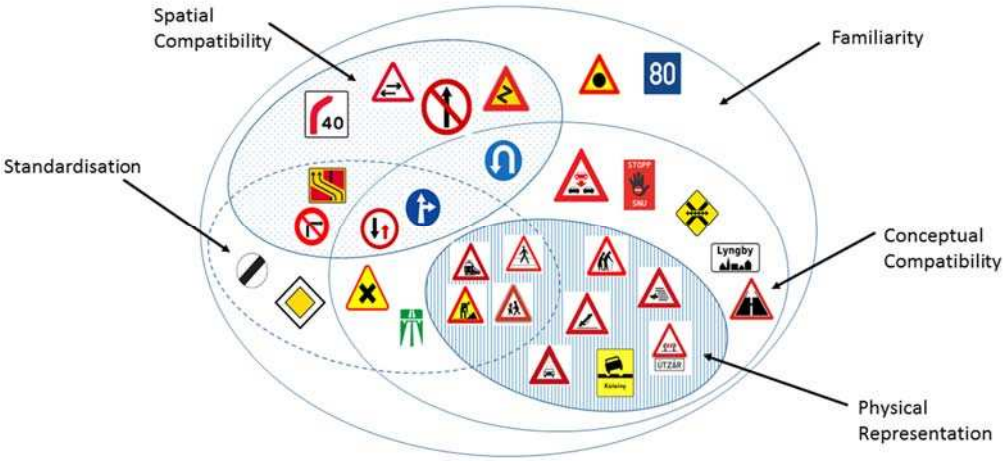

Figure 2: Choice of traffic signs corresponding to multiple ergonomic principles of symbol design

Respondents were residents of the UK, Poland and Germany. The use of the selected signs in each of the three countries is shown in Figure 3. Thirteen signs are not used in any of the three countries. One sign is unique to Germany, two signs unique to each Poland and United Kingdom. One traffic sign is common in Poland and UK, three in Poland and Germany. Nine signs are used in all three countries.

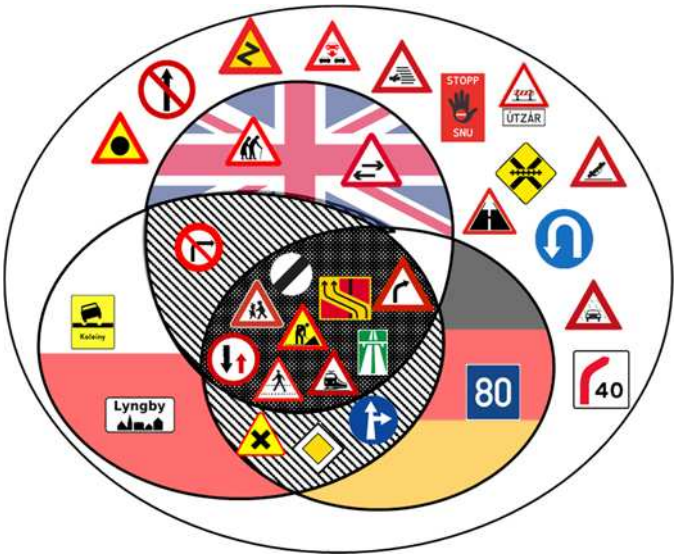

Figure 3: Use of the selected traffic signs in each of the surveyed countries

The survey was developed in the three different languages and distributed via social media e.g. Facebook and Twitter. The first part of the survey sought demographic information regarding gender, age, driving experience, and frequency of driving (in their home as well as in foreign countries). In addition, the location of where drivers gained their licence was requested. Then, participants were presented with the 31 road signs and asked to provide the meaning of each. Completing the questionnaire took between 20 and 25 minutes.

Data coding

The responses were categorised as 'wrong' [0 points], 'partially correct', [0.5 points] and 'correct', [1 point]. The responses were coded by one researcher. They were moderated (random sampling) by a second researcher. There were only a few instances where further discussion was required to enable a consensus to be had. The response was coded 'Wrong' where a traffic sign was not understood or misunderstood in a way that safety might be affected (e.g. 'U-turn allowed' instead of 'U-turn mandatory'. The coding of 'Partially correct' was used when a traffic sign was not entirely correctly understood, and might have only a minor negative impact on traffic safety (e.g. dual carriageway instead of motorway). A response was coded 'correct' if the traffic sign was understood according to the definition in the relevant highway-code.

Results

A total of 127 participants completed the survey, see Table 2. A higher number of respondents resided in Germany, compared to either the UK or Poland, and less driving abroad was undertaken by the UK respondents.

Table 2: Sample demographics

	GERMANY	POLAND	UNITED KINGDOM
n	66	31	30
% female	39%	46%	44%
% Driven abroad	70%	62%	20%

The overall response accuracy results are shown in Table 3. Approximately 60% of signs were fully correctly identified, similar to findings by Shinar et al. (2003).

Table 3: Response accuracy by country

COMPRHENSION	GERMANY	POLAND	UNITED KINGDOM	TOTAL
wrong	26.5%	26.7%	35.3%	28.7%
partially correct	12.3%	10%	14.8%	12.3%
correct	61.1%	63.3%	49.9%	59%

The proportion of correct and partially correct and incorrect responses for each sign, across all three countries is shown in Figure 4. There was a varying pattern of comprehension across road signs, ranging from 4%-99%.

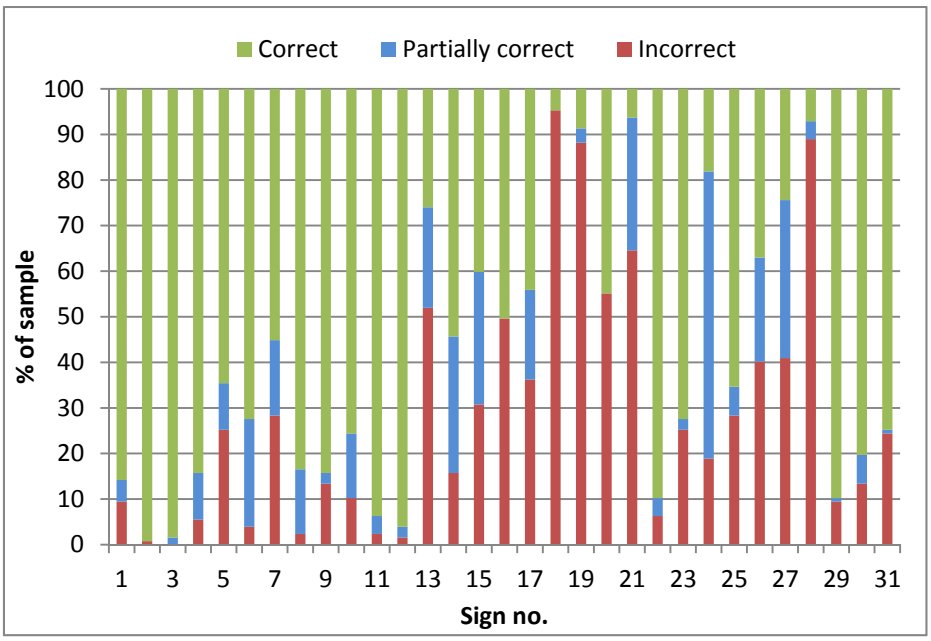

Figure 4: Answers rated 'correct', 'partially correct' or 'incorrect'

Logistic regression was performed to establish the contribution of demographic variables and ergonomic principles to drivers' ability to correctly identify the traffic signs. A test of the full model against a constant only model was statistically significant, indicating that, overall, the predictors reliably distinguished between those who answered correctly and those who did not (χ^2 = 457.35, df = 6, p < .000). Prediction success for correct answers was 80% and 65% for the model overall. Individual significant predictors were Number of ergonomic principles (p<.001), Gender (p<.001) and Country of residence (p<.001). Age and Frequency of driving abroad were not significant predictors. The parameter estimates are shown in Table 4. Each of the explanatory variables (Number of Ergonomic Principles, Gender, Country of Residence) was assigned a reference category, against which the other categories are compared. For example, for the variable "Number of Ergonomic variables", the reference category was four, and the effect of a sign having one, two or three ergonomic principles was evaluated against this.

The positive B values indicate that the responses coded as incorrect were more likely to be those relating to signs with 1, 2 or 3, ergonomic principles (compared to the reference category of 4 principles). Adjusting for Age and Country of Residence, the Exp(B) values indicate that when only one ergonomic principle was present, responses were 14.318 times more likely to be incorrect. Where two principles are incorporated, this reduced to 3.988 times as likely and when three were present, the effect was non-significant (all compared to having four principles). This can be interpreted as indicating that three is the minimum number of ergonomic principles to strive for.

With regards gender, Females were more likely to feature in the incorrect response dataset (by a factor of 1.268). Finally the negative B value indicates that those residing in Germany or Poland, were less likely to present an incorrect answer compared to those in the UK (by factors of around 60% and 52% respectively).

Table 4 Logistic regression results – number of ergonomic principles and demographics

Explanatory variable		B	Wald	df	Sig	Exp(B)
Number of Ergonomic principles (reference =4)						
	1	2.661	148.157	1	.000	14.318
	2	1.383	71.199	1	.000	3.988
	3	.316	3.493	1	.062	1.372
Gender (reference=Male)						
	Female	.237	11.517	1	.001	1.268
Country of Residence (reference =UK)						
	Germany	-.497	34.728	1	.000	.608
	Poland	-.638	41.287	1	.000	.528

Having established that the number of ergonomic principles significantly affects comprehension, a further regression model was run to investigate the relative importance of each of the principles. With familiarity being difficult to ascertain (drivers could have been exposed to signs by a varying degree), the remaining four principles were entered into the regression. Table 5 shows that the inclusion of the principles has a varying effect on comprehension. Whilst all the principles have a positive effect on comprehension (as noted by the positive B values), the effects were variable. Conceptual Compatibility was the only principle that was not statistically significant (p=0.069).

Table 5 Logistic regression results – importance of each ergonomic principle

Factor	B	Wald	df	Sig	Exp(B)
Conceptual Compatibility	.160	3.318	1	.069	1.174
Physical Compatibility	.861	74.761	1	.000	2.366
Spatial Compatibility	.855	96.195	1	.000	2.351
Standardisation	1.597	429.408	1	.000	4.940

When the effects of the remaining principles were held constant, the odds of a respondent being able to correctly identify a sign is just over double when either the principles of Physical or Spatial Compatibility are included (ExpB = 2.366 and 2.351 respectively). However, the principle of Standardisation has the greatest role to play in correct comprehension – its presence increases the likelihood of providing a correct response by almost five times (ExpB = 4.94).

Conclusions and recommendations

This survey was undertaken not only to ascertain the importance of ergonomic principles of road sign design, but also to quantify the contribution of each of the principles to sign comprehension. The results showed there to be great variability in comprehension of the sign meaning, with some signs almost completely misunderstood (or unknown) and others having a high level of accurate comprehension. Female participants and those residing in the UK showed significantly lower understanding, perhaps with the latter attributed to less driving on mainland Europe. The results show that, optimally, three or four of the ergonomic principles should be incorporated into a sign for maximum comprehension. In addition, the principle of standardisation, which refers to the use of common colours and shapes, is the most influential on comprehension.

There are a number of implications relevant to drivers, road sign designers and policy makers. Firstly it could be argued that drivers travelling outside their country of residence should be responsible for learning the road signs related to the destination

country. This is particularly more so given the Cross-Border Enforcement Directive. In such a utopian paradigm drivers would be able to instantly recall a sign's meaning – this might not be possible in situations where a driver is experiencing stress or high workload. However, when driving in a different country, familiarity with the road will be low. Matthews et al. (1999) reported that increased stress-related tension can occur while driving on unfamiliar roads and Hill and Boyle (2007) found that females are more likely to report higher levels of stress than males. Some research suggests that professional drivers, such as bus and coach drivers, experience higher levels of cortisol at work than they do in their leisure time (Aronsson and Rissler, 1998; Sluiter, van der Beek and Frings-Dresen, 1998). There exist no experimental studies, as far as the authors are aware, which investigate the levels of arousal that drivers experience when driving in an unfamiliar country; self-reports are more common, however (e.g. Wu, 2015). The results of the current study indicate that drivers can have difficulties understanding the meaning of road signs, and coupled with the studies that report higher levels of stress on unfamiliar roads, comprehension may be further compromised via poorer recall.

To reduce such problems, it is recommended that road signs incorporate at least three ergonomic principles, with adherence to standardisation being crucial for maximum comprehension. Thus, the consistent use of shape and colour for instruction, warning and information signs within a country is recommended, as well as between countries. Consistency in design has been shown to improve driver's adherence to traffic regulations, commonly known as the self-explaining road (Theeuwes and Godthelp, 1995). This concept advocates a traffic environment that elicits safe driving behaviour simply by its design.

Summary

Cross-border road traffic continues to grow (8.8% annually between Spain and France) and the need for further harmonisation as reported in this study underlines the claims made by Shinar et al. (2003) and Räsänen and Horberry (2006). For policy makers and sign designers, the recommendations from the study are clear incorporating three ergonomic principles, where possible, will be maximally advantageous for sign comprehension; and as a bare minimum use European standardised concepts.

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