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Using a traffic climate scale to understand drivers' perceptions of their traffic system: An examination of measurement invariance across eight countries

İbrahim Öztürk [a,*], Ruth Madigan [a], Yee Mun Lee [a], Elina Aittoniemi [b], Esko Lehtonen [b], Natasha Merat [a]

[a] Institute for Transport Studies, University of Leeds LS2 9JT Leeds, United Kingdom
[b] VTT Technical Research Centre of Finland Ltd., Tekniikantie 21 02150 Espoo, Finland

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ABSTRACT

Measuring road users' attitudes towards the traffic system, often referred to as traffic climate, can provide valuable insights into the experiences of road users and guide the adaptation of road safety measures to the local context. For such a purpose, it is essential to evaluate the psychometric properties of the measurement instrument, to obtain information on its' validity and reliability, and its suitability for cross-country comparisons. In this study, conducted as part of the Hi-Drive project (hi-drive.eu), we examined the psychometric properties of the Traffic Climate Scale (TCS) across 7896 respondents from eight countries: the United States, the United Kingdom, Germany, Sweden, Poland, Greece, China, and Japan. The TCS demonstrated a consistent factorial structure across all eight countries, showing configural and metric invariance, as well as partial scalar invariance, indicating high reliability and validity. The results also revealed significant differences among countries, with the traffic climate in Greece being perceived as highly demanding and less functional than other countries. In contrast, the traffic climate in countries like Japan and Sweden was perceived as less demanding and more functional. Age, gender, and exposure to different traffic situations had a limited impact on the perceived traffic climate, suggesting a relatively consistent perception of traffic climate across. The results indicated that the TCS is a reliable instrument for measuring the perceived traffic climate. The use of the measurement could provide more information on the experience of road users in the traffic system and guide the adaptation of road safety measures to the local context.

1. Introduction

For many years, studies have investigated how latent factors, i.e., attitudes and behaviours of road users such as pedestrians (e.g., McIlroy et al., 2020; Oviedo-Trespalacios et al., 2021), drivers (e.g., Nguyen-Phuoc et al., 2020; Wallén Warner et al., 2009) and cyclists (e.g., Kummeneje & Rundmo, 2020; Yannis et al., 2020) influence road safety. While studies conducted within a single country provide valuable information regarding intra-country variability, examining measurements and constructs across multiple countries offers a broader perspective and highlights the areas in which cultural differences may become relevant. Such cross-cultural research

* Corresponding author at: Institute for Transport Studies, University of Leeds, LS2 9JT Leeds, United Kingdom.
E-mail address: i.ozturk@leeds.ac.uk (İ. Öztürk).

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(e.g., Nordfjærn et al., 2011; 2014; Oviedo-Trespalacios et al., 2021; Yannis et al., 2020) can also shed light on variations across countries and shows the importance of comparing data across settings to identify commonalities and unique factors. In order to draw meaningful cross-cultural conclusions (Putnick & Bornstein, 2016; Van de Schoot et al., 2015), it is important to establish a robust and stable measurement of latent factors across different samples (e.g., Castro et al., 2024; Damjanović et al., 2022; Stephens et al., 2024).

1.1. Perception of traffic climate

A traffic system consists of several components, including different groups of road users, modes of transport, and infrastructure characteristics. Within this complex structure, road users' attitudes and behaviours influence their perception of traffic culture, which has been shown to be an important influence on road safety (e.g., Nævestad et al., 2019; Nævestad et al., 2020). Recent research has developed a number of definitions (Edwards et al., 2014) and measures of traffic culture and climate (Nævestad & Milch, 2023; Özkan & Lajunen, 2015; Stipdonk et al., 2024).

The daily experiences of road users can shape their overall perception of the traffic system, and this is often referred as the traffic climate. Traffic climate can be defined as "*the road users' (*e.g. *drivers') attitudes and perceptions of the traffic in a context (*e.g. *country) at a given point in time*" (Özkan & Lajunen, 2011, p. 188). Based on this definition, Özkan and Lajunen (unpublished) developed the Traffic Climate Scale (TCS) for measuring road users' perceptions of the traffic system. This scale (Gehlert et al., 2014; Özkan & Lajunen, unpublished) identifies three factors – *external affective demands*, *functionality*, and *internal demands* – as components of traffic climate. *External affective demands* refer to the perceived emotional involvement with the traffic system, such as perceiving the traffic system as stressful and aggressive. *Functionality* pertains to the perception of a functional traffic system, such as the perception of the traffic system as safe and well-planned. Finally, *internal demands* refer to the skills and abilities that road users perceive as necessary for using the traffic system. For example, a traffic system with high internal demands is reflected as requiring vigilance and alertness (Gehlert et al., 2014).

Earlier versions of the TCS consisted of 41 items (e.g., Gehlert et al., 2014) or 44 items (e.g., Üzümcüoğlu et al., 2019). Different versions of the TCS with varying item numbers have been used in many countries, including Germany (Gehlert et al., 2014), China (Qu et al., 2019), Türkiye (Üzümcüoğlu et al., 2019), Sweden (Öztürk et al., 2022), Israel (Kaçan Bibican, 2023), Vietman (Hoang et al., 2025), Estonia and Kosovo (Üzümcüoğlu et al., 2020), and results have consistently demonstrated the same factorial structure, with some item variations. More recently, Üzümcüoğlu et al. (2020) suggested several shorter versions of the scale, taking into account the factorial loading and the stability of the items across six countries. The optimal version, also used in this study, was identified as a 16-item scale, which was subsequently proven to be reliable in Sweden (Öztürk et al., 2022).

Previous cross-cultural comparisons of traffic climate perception have shown that variations in perceived traffic climate reflected the differences in objective and subjective road safety indicators such as the number of fatalities (e.g., Üzümcüoğlu et al., 2019). A cross-cultural comparison of China and Türkiye (Üzümcüoğlu et al., 2019) showed that the traffic system in China was perceived as more emotionally demanding and functional than the traffic system in Türkiye. The traffic system in Türkiye was perceived to be higher in terms of internal requirements than in China. This is later reflected in drivers from both countries reporting more violations. In another study, Öztürk et al. (2022) compared the perceived traffic climate in Türkiye and Sweden. They observed that the traffic system in Sweden was considered more functional and less demanding, both internally and externally, compared to Türkiye. Similarly, Israeli participants rated their traffic system to be less demanding than the Turkish participants (Kaçan Bibican, 2023). These findings match objective road safety indicators (WHO, 2018), such as the lower number of road fatalities in Sweden and Israel than in Türkiye.

The experience of road users in traffic may change over time. Therefore, it can be argued that certain demographic variables, such as age, gender or exposure, may have an impact on the perception of the traffic climate. The majority of studies have found weak or no relations between traffic climate factors and age (e.g., Chu et al., 2019; Öztürk et al., 2022), as well as weak or no differences between males and females (e.g., Chu et al., 2019; Üzümcüoğlu & Özkan, 2019) and exposure measures such as kilometres driven, crashes (e.g., Öztürk et al., 2022) or driving frequency (Kaçan Bibican, 2023). However, once again, this varies across the three factors making up the TCS. For example, while studies showed no significant correlations of age with external affective demands (Chu et al., 2019; Zhang et al., 2018) or internal requirements (Chu et al., 2019; Öztürk et al., 2022), the correlations between age and functionality ranged from positive (Zhang et al., 2018) to negative (Chu et al., 2019; Öztürk et al., 2022). In a study conducted in China, Atombo and Wu (2022) found that female and male drivers did not differ in their perception of internal requirements and external affective demands of the traffic system. However, female drivers perceived the traffic system as more functional than male drivers. Furthermore, studies have also shown that age and gender are related to behaviours, attitudes and crash involvement (e.g., Bogdan et al., 2016; de Winter & Dodou, 2010; Lucidi et al., 2019; Mannocci et al., 2019). In consideration of these issues, in the present study, the relationships between perception of traffic climate and age, gender, and exposure to different traffic situations have been examined separately in each country.

Research has revealed associations between perceptions of traffic climate and driver behaviours, with studies finding links between negative traffic climate factors e.g., high ratings of external demands, or low ratings of functionality, and aberrant driving behaviours, such as errors and violations (e.g., Atombo & Wu, 2022; Chu et al., 2019; Hoang et al., 2025; Gehlert et al., 2014; Üzümcüoğlu et al., 2019; Öztürk et al., 2024). On the other hand, there is evidence of the beneficial effects of a positive traffic climate e.g. high functionality or low external affective demands, on positive behaviours such as increased prosocial activities (e.g., Atombo & Wu, 2022; Chu et al., 2019; Üzümcüoğlu et al., 2019). Thus, gaining an understanding of the traffic climate across different countries may provide insights into how to promote more prosocial and positive driving behaviours.

Perceptions of traffic climate are also associated with attitudes towards certain modes of transportation, such as automated vehicles (e.g., Qu et al., 2019; Öztürk et al., 2023) and bike sharing (e.g., Ge et al., 2020). However, results have not been consistent across different countries, with Öztürk and colleagues (2023) showing a positive relationship between perceived external affective demands and preferences for higher levels of automation in Türkiye, while there was no relationship in Sweden. Consistent with the findings from Türkiye, in another study conducted in China, Qu et al. (2019) found that road users who perceived the traffic system as more emotionally demanding were less likely to be concerned about the potential problems automated vehicles might have/cause.

This brief review of studies using TCS shows that it correlates with several factors relevant to road safety and the introduction of automated vehicles into traffic systems. It is, therefore, important to understand whether the psychometric properties or interpretations of these scales are the same across countries, to ensure the meaningful use of the measurement.

1.2. Rationale and objectives of the study

Although the scale has been tested in many countries (e.g., Üzümcüoğlu et al., 2020), to the best of our knowledge, the measurement invariance of the TCS has not been examined. With this in mind, the first objective of the present study is to examine the factorial structure of the Traffic Climate Scale across eight countries (United Kingdom, United States, Germany, Sweden, Poland, Greece, China, and Japan). The countries included in this survey have differences in terms of road safety indicators, and given the previously mentioned links between TCS and objective road safety indicators (e.g., Üzümcüoğlu et al., 2019), this cross-country comparison is important. For example, the estimated fatality rates per 100,000 people in 2021 were 2.1 for Sweden, 2.4 for the UK, 3.3 for Germany, 2.7 for Japan, 7.3 for Greece, 6.5 for Poland, 14.2 for the US, and 17.4 for China according to the World Health Organization (2023). In addition, Moszoro and Soto (2022) calculated the adjusted mean speed for travel between the largest city and other cities in each country, taking into account geographical characteristics as an indicator of road quality. Based on this calculation, the adjusted mean speeds (km) were 95 for the United Kingdom, 114 for the United States, 107 for Germany, 102 for Sweden, 98 for Poland, 115 for Greece, 98 for China, and 92 for Japan. The differences observed suggest that road safety and traffic systems differ between the selected countries. Consequently, evaluating road users' perceptions of the traffic climate across countries with differing road safety profiles will provide a robust indicator of the scale's reliability.

The second objective of the study is to examine the measurement invariance of the TCS across different samples. The establishment of measurement invariance at different levels reflects a degree of equivalence across samples. In this way, the equivalence of the cross-culturally assessed construct can be measured (Boer et al., 2018). A lack of measurement invariance can lead to misinterpretation of results across samples. In this regard, no previous research has focused on the measurement invariance of the TCS. Following this, the third objective of the study is to examine how participants' perception of the traffic climate differs across countries.

Finally, as previously outlined, there exists limited knowledge regarding the association between demographic factors and perceptions of traffic climate. Therefore, the fourth and final objective of the study is to examine differences in perceptions of traffic climate by age, gender, and exposure to different traffic situations in each individual country. Given the study's objectives, we did not examine the measurement structure with specific hypotheses in mind.

2. Method

2.1. Survey design and data collection

The data was collected as part of the Global User Survey of the Hi-Drive project (HORIZON Europe – Project No 101006664), which was designed to collect road users' views on automated driving. The questionnaire was developed in English and translated into other languages by a professional translation agency. Given the nature of the scale content (predominantly comprising adjectives), no item modifications were deemed necessary. No feedback or translation ambiguity has been reported by the company/panel. The data collection was performed by a Finnish market research company, Taloustutkimus Oy, in collaboration with its international market research network in May-June 2023. The participants were recruited via online panels of the respective countries. The members of the online panels were compensated either with a small amount of money, or they were able to win prizes based on their participation to the online panels. The data was recruited from the online panels so that the age groups 18–38, 39–55, and 56–75 were equally represented, and all age groups contained approximately half women and half men. Participants reported their age as a continuous variable, and is treated as such in the analysis. The samples were geographically representative within their countries. The complete

Table 1
Age and gender distribution of the final sample.

Country	*Age*					*Gender*			
	N	*M*	*SD*	*Minimum*	*Maximum*	Male	Female	Other	Prefer not to say
United Kingdom	954	49.42	14.65	18	75	490	463	0	1
United States	1060	50.11	15.54	18	75	536	521	1	2
Germany	949	48.73	14.54	18	75	487	461	1	0
Sweden	1000	49.30	15.61	18	75	519	478	2	1
Poland	967	46.22	13.87	18	75	494	471	2	0
Greece	937	46.84	13.38	19	75	489	446	1	1
China	1057	46.26	12.51	19	71	540	513	4	0
Japan	972	48.41	13.50	19	75	496	473	1	2

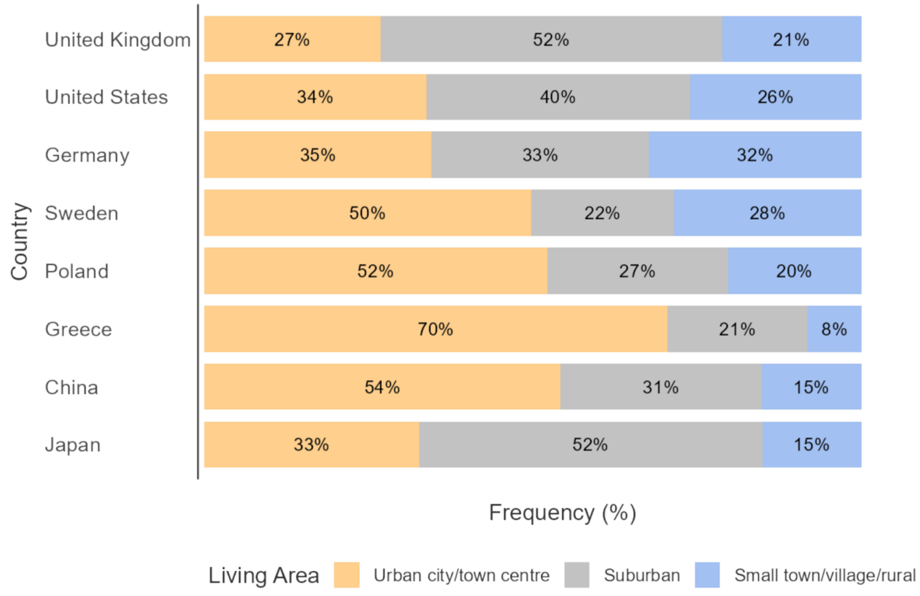

Fig. 1. Living area.

questionnaire comprised 13 sections, including the informed consent and debriefing form. Each section (of which the TCS is one) was presented on a separate page. Additional sections addressed factors such as willingness to use automated driving systems and expectations from automated driving systems. The entire study took approximately 20 min to complete. Considering the ease of answering the majority of questions and the overall length, the study is deemed to be of acceptable duration for a panel study (Revilla & Höhne, 2020).

2.2. Sample

The final sample size comprised 7896 drivers from eight countries. Participants without a driving licence were excluded to ensure a sample of participants who had received formal driving training and possessed knowledge of driving and traffic systems. The age and gender (see Table 1) and living area (Fig. 1) distributions are presented below. The study complied with the guidelines of the Finnish National Board on Research Integrity TENK,[1] and all participants provided informed consent. In Finland, neither legislation nor TENK's guidelines require ethical review by an ethics committee if the participants are adults who give informed consent to participate, and the study 1) does not intervene with the physical integrity of participants, 2) does not expose the participants to strong stimuli, 3) does not cause mental harms exceeding normal daily life, 4) and does not compromise the safety of the involved persons.

2.3. Traffic climate scale

Road users' perception of the traffic system was measured using the short version of the Traffic Climate Scale (Üzümcüoğlu et al., 2020) with 16 items. Individuals were asked to rate the traffic system, environment, and atmosphere of their daily traffic environment on a six-point Likert scale ranging from 1 (does not describe at all) to 6 (describes completely). This short version of the scale (see 3.1) consists of three factors: external affective demands, functionality, and internal requirements (Üzümcüoğlu et al., 2020).

2.4. Exposure to different driving situations

To assess drivers' exposure to different driving conditions, participants were requested to indicate the frequency with which they encounter eight distinct potentially challenging driving situations (selected based on the Operational Design Domain challenges of the Hi-Drive project). Responses were recorded on a 5-point Likert scale ranging from 1 (Nearly every day) to 5 (Less often or never), representing participants' exposure to the situations. The situations and frequency of each for the pooled dataset are presented in Table 2 (presented separately for each country in Appendix A). The scores are reversed; thus, lower values indicate lower frequency.

[1] https://tenk.fi/sites/default/files/2021–01/Ethical_review_in_human_sciences_2020.pdf.

2.5. Data and analysis

Data were analyzed using JASP 0.17.3.0 and Jamovi 2.5.6. First, participants without a driving license were excluded from the sample. After data cleaning, to examine the first objective – examining the psychometric properties of the Traffic Climate Scale across eight countries, confirmatory factor analyses (CFA) were performed for each country separately to test the measurement model proposed by Üzümcüoğlu et al. (2020). The comparative fit index (CFI), root mean square error of approximation (RMSEA), $\chi 2$/degrees of freedom ratio, and standardized root mean square residual (SRMR) values were used to determine model fit. A model with a CFI greater than 0.90, a RMSEA less than 0.10, and an SRMR less than 0.08 was accepted as a good model (Hu & Bentler, 1999; Russell, 2002; Schermelleh-Engel et al., 2003). The CFA results for each country are reported in section 3.1 following the recommendations (Jackson et al., 2009; Jeong & Lee, 2019; Rutkowski & Svetina, 2014).

Confirmatory factor analyses were conducted separately for each country, after which measurement invariance (configural, metric, and scalar) was tested (section 3.2) to examine the second objective. Configural invariance tested the invariance of the overall factor structure across the eight countries. Metric invariance examines the invariance of factor loadings across countries. Metric invariance provides information about the contribution of each item to the latent constructs. Finally, scalar invariance examines the invariance of item intercepts across countries (Furr, 2021; Putnick & Bornstein, 2016). The obtained goodness of fit indices (CFI > 0.90, RMSEA < 0.08) indicated a good model (Hu and Bentler, 1999). Chi-squared comparisons were not performed due to the sensitivity to large sample sizes (van de Schoot et al., 2012). As the sample size increases, the likelihood of rejecting invariance also increases (Chen, 2007). Considering this, we followed ΔCFI ≥ 0.010 and ΔRMSEA ≥ 0.015 for deciding on measurement invariance (Chen, 2007).

After establishing the comparability of the TCS across eight countries, to test the third objective of the study – comparing the perceived traffic climate between countries, a single multivariate analysis of covariance (MANCOVA) with three dependent variables (external affective demands, functionality, internal requirements) was conducted to test for country-level differences in the three factors of the TCS (Section 3.3). Age and gender (binary coded) were included as control variables.

The final analysis focused on the fourth objective of the study i.e., to examine differences in perceptions of traffic climate by age, gender, and exposure to different traffic situations in each individual country. A linear regression was used, where age (as a continuous variable), gender (binary coded), and exposure to traffic situations were entered into the model together (Section 3.4). Due to limited sample sizes in the “other” and “prefer not to say” categories (see Table 1), gender was tested as a binary variable (male vs. female).

3. Results

3.1. Confirmatory factor analyses

The original three-factor structure across the United Kingdom, United States, Germany, Sweden, Poland, Greece, China, and Japan (Table 3) showed acceptable fit indices in each country.

The Cronbach’s alpha values for external affective demands were 0.91 for the United Kingdom, 0.91 for the United States, 0.89 for Germany, 0.91 for Sweden, 0.90 for Poland, 0.93 for Greece, 0.90 for China, and 0.87 for Japan.

The Cronbach’s alpha values for functionality were 0.77 for the United Kingdom, 0.81 for the United States, 0.82 for Germany, 0.79 for Sweden, 0.84 for Poland, 0.80 for Greece, 0.83 for China, and 0.85 for Japan.

The Cronbach’s alpha values for internal requirements were 0.86 for the United Kingdom, 0.83 for the United States, 0.88 for Germany, 0.73 for Sweden, 0.85 for Poland, 0.86 for Greece, 0.78 for China, and 0.79 for Japan.

3.2. Measurement invariance testing

The configural invariance was established for the three-factor model across the eight countries ($\chi^2(808) = 5393.13$, $p < 0.001$, CFI $= 0.925$, TLI $= 0.911$, RMSEA $= 0.027$). The metric invariance model was retained, and the model showed a good fit ($\chi^2(899) = 5970.556$, $p < 0.001$, CFI $= 0.917$, TLI $= 0.912$, RMSEA $= 0.027$). For the scalar invariance, where Sweden was chosen as the reference group (due to the fact that the TCS was previously used in Sweden, see Öztürk et al., 2022), the model deteriorated as a result of the equality constraints of the intercepts and showed non-invariance of the intercepts ($\chi^2(990) = 8707.62$, $p < 0.001$, CFI $= 0.874$, TLI $= 0.878$, RMSEA $= 0.031$). Following that, partial scalar invariance was tested by releasing equality constraints of the intercepts of items “depends on luck”, “pressurizing”, “irritating”, “annoying”, “planned”, “harmonious”, “functional”, and “demands alertness”. The

Table 2
Frequency of exposure to each traffic situations.

	Mean	SD
1. Entering and exiting motorways via on– and off-ramps.	2.708	1.346
2. Driving in congested traffic	3.200	1.341
3. Driving in urban centres among pedestrians and cyclists	3.321	1.344
4. Parking in indoor parking lots	2.682	1.406
5. Driving through tunnels	2.258	1.311
6. Driving in intersections and roundabouts	3.511	1.327
7. Overtaking slower vehicles	3.247	1.328
8. Driving in adverse weather conditions (rain, snow, fog)	2.527	1.200

Table 3
Factor loadings of the TCS across the eight countries.

Country:		**United Kingdom**			**United States**			**Germany**			**Sweden**		
Factor	**Item**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**
External affective demands	Aggressive	0.99	0.04	0.73	1.08	0.04	0.74	1.03	0.04	0.73	1.06	0.04	0.77
	Stressful	1.09	0.04	0.81	1.18	0.04	0.81	1.16	0.04	0.82	1.06	0.04	0.78
	Depends on luck	0.81	0.04	0.61	0.86	0.04	0.57	0.78	0.04	0.56	0.75	0.04	0.55
	Pressurizing	1.05	0.04	0.78	1.03	0.04	0.73	1.14	0.04	0.80	0.97	0.04	0.72
	Chaotic	1.08	0.04	0.78	1.19	0.04	0.81	1.12	0.04	0.79	1.08	0.04	0.80
	Irritating	1.12	0.04	0.81	1.21	0.04	0.81	1.14	0.04	0.82	1.10	0.04	0.82
	Time-consuming	0.89	0.04	0.68	1.00	0.04	0.69	0.97	0.04	0.69	0.92	0.04	0.67
	Annoying	1.10	0.04	0.81	1.25	0.04	0.83	0.55	0.04	0.42	1.11	0.04	0.83
Functionality	Planned	0.83	0.04	0.66	0.87	0.04	0.66	0.87	0.04	0.66	0.84	0.04	0.66
	Harmonious	0.61	0.04	0.51	0.80	0.04	0.61	0.79	0.04	0.63	0.84	0.04	0.67
	Safe	0.87	0.04	0.72	0.93	0.04	0.72	0.95	0.04	0.77	0.83	0.04	0.69
	Functional	0.84	0.04	0.69	0.94	0.04	0.74	0.86	0.04	0.69	0.90	0.04	0.75
	Free-flowing	0.66	0.04	0.56	0.88	0.04	0.69	0.84	0.04	0.70	0.69	0.04	0.53
Internal requirements	Demands alertness	1.14	0.04	0.84	1.06	0.04	0.76	1.15	0.04	0.86	0.84	0.04	0.66
	Demands caution	1.01	0.04	0.77	1.12	0.04	0.80	1.06	0.04	0.80	1.00	0.04	0.76
	Requires vigilance	1.14	0.04	0.84	1.16	0.04	0.80	1.19	0.04	0.88	0.90	0.05	0.65
χ^2		$\chi^2(101) = 740.22, p < 0.001$			$\chi^2(101) = 820.59, p < 0.001$			$\chi^2(101) = 706.29, p < 0.001$			$\chi^2(101) = 733.87, p < 0.001$		
CFI		0.91			0.92			0.92			0.91		
RMSEA		0.08			0.08			0.08			0.08		
SRMS		0.07			0.07			0.07			0.06		

Country:		**Poland**			**Greece**			**China**			**Japan**		
Factor	**Item**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**
External affective demands	Aggressive	0.97	0.04	0.73	1.10	0.04	0.74	1.15	0.04	0.76	0.72	0.03	0.65
	Stressful	1.03	0.04	0.77	1.22	0.04	0.81	1.14	0.04	0.78	0.93	0.03	0.77
	Depends on luck	0.73	0.04	0.56	0.81	0.04	0.57	0.56	0.04	0.41	0.72	0.04	0.61
	Pressurizing	0.98	0.04	0.76	1.19	0.04	0.83	1.13	0.04	0.77	0.86	0.04	0.70
	Chaotic	0.98	0.04	0.76	1.26	0.04	0.82	1.16	0.04	0.78	0.74	0.03	0.68
	Irritating	1.06	0.04	0.82	1.29	0.04	0.85	1.17	0.04	0.79	0.83	0.03	0.74
	Time-consuming	0.75	0.04	0.61	1.19	0.04	0.79	0.91	0.04	0.65	0.75	0.03	0.69
	Annoying	1.05	0.04	0.81	1.20	0.04	0.83	1.19	0.04	0.82	0.67	0.03	0.60
Functionality	Planned	0.82	0.04	0.69	0.76	0.05	0.56	0.69	0.03	0.61	0.85	0.03	0.77
	Harmonious	0.86	0.04	0.73	1.04	0.04	0.76	0.89	0.03	0.75	0.83	0.03	0.79
	Safe	0.92	0.03	0.80	1.01	0.04	0.75	0.83	0.03	0.72	0.77	0.03	0.70
	Functional	0.86	0.03	0.75	0.94	0.04	0.70	0.85	0.03	0.73	0.73	0.03	0.69

(*continued on next page*)

Table 3 (*continued*)

Country:		Poland			Greece			China			Japan		
Factor	**Item**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**	**Estimate**	**Std. Error**	**Std. Est.**
	Free-flowing	0.67	0.04	0.58	0.69	0.04	0.55	0.84	0.04	0.69	0.72	0.03	0.73
Internal requirements	Demands alertness	0.96	0.04	0.77	1.07	0.04	0.80	0.92	0.04	0.73	0.84	0.04	0.73
	Demands caution	1.02	0.03	0.84	1.11	0.04	0.82	0.84	0.04	0.67	0.87	0.04	0.72
	Requires vigilance	0.99	0.03	0.82	1.11	0.04	0.84	1.01	0.04	0.79	0.96	0.04	0.79
χ^2		$\chi^2(101) = 589.01$, $p < 0.001$			$\chi^2(101) = 342.25$, $p < 0.001$			$\chi^2(101) = 735.91$, $p < 0.001$			$\chi^2(101) = 730.44$, $p < 0.001$		
CFI		0.94			0.97			0.92			0.91		
RMSEA		0.07			0.05			0.08			0.08		
SRMS		0.07			0.04			0.07			0.06		

partial invariance model fits the data significantly better than the full scalar model ($\chi^2(934) = 6539.30$, $p < 0.001$, CFI = 0.909, TLI = 0.906, RMSEA = 0.028), and supported partial invariance where at least two indicators per factor were kept equal (Cieciuch & Davidov, 2015).

3.3. Cross-country comparison of traffic climate perception

A series of multivariate analyses of covariance (MANCOVA) found that all three factors of the TCS showed country-level differences (Table 4).

For ***external affective demands*** (Fig. 2), pairwise comparisons showed that the traffic climate in Greece was perceived as significantly more demanding than other countries, and Sweden and Japan were perceived to be the least demanding countries.

In terms of ***functionality*** (Fig. 3), participants from China perceived the traffic system as more functional than in other countries; and the traffic system in Greece was perceived as less functional than all other countries except Japan.

In terms of ***internal requirements***, participants from Greece were the ones who felt that the traffic system required the most vigilance. On the other hand, the perceived level of internal requirements was lowest in Japan (Fig. 4).

3.4. Effects of age, gender, and traffic situations on the perception of traffic climate

Twenty-four separate linear regression analyses (Table 5-7) were carried out to investigate the associations between different factors (age, gender, and exposure to different traffic situations) and the three dimensions of the TCS in eight countries separately.

For ***external affective demands***, the models explained ranged from 1 % to 11 % of the variance (Table 5). As age increased, the perception of external affective demands decreased in all countries except Poland, China, and Greece, whereas there were no significant gender effects in all countries. Higher exposure to different traffic situations was associated with higher external affective demands.

For ***functionality***, the models explained ranged from 0.0 % to 4 % of the variance (Table 6) and were significant in all countries except for Sweden and Greece, where increasing age and exposure to different traffic situations was associated with increased functionality.

For ***internal requirements***, the models explained ranged from 0 % to 5 % of the variance (Table 7) and were significant in each country except China. The perception of internal requirements increased with age in all countries (except for China) and increased with exposure to different traffic situations in all countries (except for Sweden, China, and Japan). In terms of gender, females in Sweden and Greece perceived higher internal requirements than males. There were no other significant gender effects.

4. Discussion

The present study examined the factorial structure and measurement invariance of the Traffic Climate Scale in a sample of 7896 drivers from eight countries, to ensure the reliability and validity of this scale in providing a standardized tool across different cultural contexts. Initially, we conducted an examination of the factorial structure across eight countries (Objective 1). Following the

Table 4
Comparison of the TCS factors across eight countries.

Dimension	*Country*	*M*	*SD*	*F(7, 7867)*	*p*	η_p^2
External Affective Demands	United Kingdom	2.96	1.06	49.35	< 0.001	0.042
	United States	3.10	1.16			
	Germany	2.97	1.04			
	Sweden	2.79	1.06			
	Poland	3.12	1.00			
	Greece	3.60	1.20			
	China	3.23	1.11			
	Japan	2.91	0.83			
Functionality	United Kingdom	3.66	0.88	132.68	< 0.001	0.106
	United States	3.75	0.98			
	Germany	3.84	0.95			
	Sweden	3.65	0.92			
	Poland	3.92	0.90			
	Greece	3.39	0.99			
	China	4.48	0.90			
	Japan	3.52	0.84			
Internal Requirements	United Kingdom	4.15	1.19	84.10	< 0.001	0.070
	United States	4.18	1.22			
	Germany	4.38	1.20			
	Sweden	4.00	1.07			
	Poland	4.14	1.07			
	Greece	4.55	1.18			
	China	4.22	1.05			
	Japan	3.43	0.99			

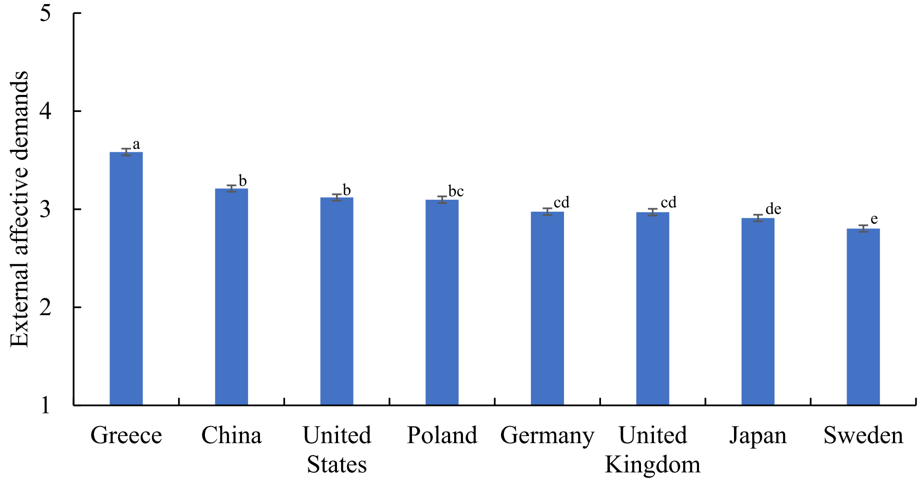

Fig. 2. External affective demands by the country (ordered from highest to lowest estimated marginal means, with standard error bars). Means with different superscript letters over bars indicate significant difference ($p < 0.05$) between the countries.

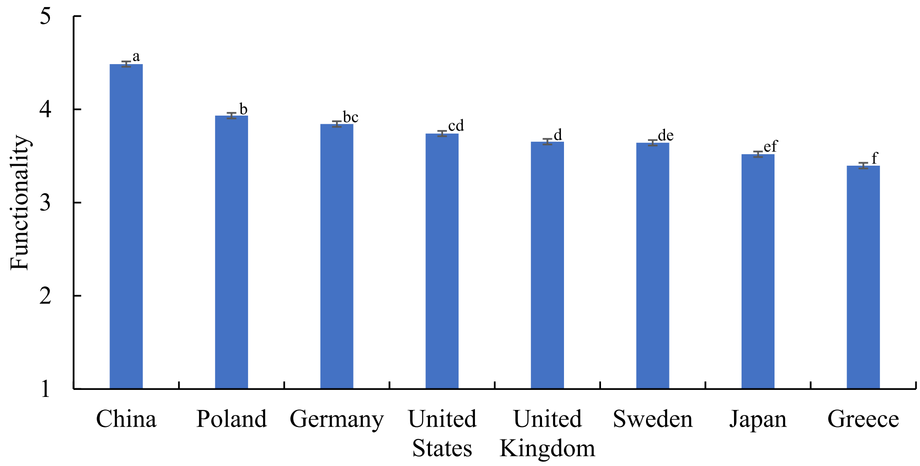

Fig. 3. Functionality by the country (ordered from highest to lowest estimated marginal means, with standard error bars). Means with different superscript letters over bars indicate significant difference ($p < 0.05$) between the countries.

establishment of a valid factorial structure, measurement invariance for the perceived traffic climate was analysed (Objective 2), and subsequently, mean comparisons of the traffic climate factors were examined across the eight countries (Objective 3). Finally, the effects of age, gender, and exposure to traffic situations in each country were examined using linear regression (Objective 4).

For the first objective of the study, confirmatory factor analysis revealed that the TCS had a reliable construct structure across samples from eight countries. This supports the results obtained in previous studies with smaller sample sizes (Gehlert et al., 2014; Üzümcüoğlu et al., 2020; Kaçan Bibican, 2023; Öztürk et al., 2022).

For the second objective of the study, the invariance results indicated that the constructs of the Traffic Climate Scale were similar across the eight countries and that each item contributed to the relevant factor to a similar extent. Thus, it can be concluded that the TCS can be used as a consistent measure of the perceived traffic climate in any given country or daily driving environment. As discussed by Putnick and Bornstein (2016), mean difference tests have been conducted even when there are some violations of measurement invariance, often referred to as partial invariance. In the presence of partial invariance, it is important to question the interpretation of the differences (Schmitt & Kuljanin, 2008). In this study, the TCS showed some violations of scalar invariance where the model was significantly worsened. However, considering the nature of the measurement, which aims to capture the impact of variations in geographic context and traffic planning, differences between countries are actually expected, and therefore, this violation can be accepted. Thus, our results suggest that the TCS can be used as a consistent measure of the perceived traffic climate across different countries and daily driving environments, while recognizing and accounting for certain item-level differences between countries. As a result, it can be concluded that the factors investigated in this study revealed cross-cultural meaningful comparisons based on measurement invariance results (Boer et al., 2018; Putnick & Bornstein, 2016; Van de Schoot et al., 2015).

The third objective of the study was to examine if there were cross-country differences in TCS ratings after providing evidence for

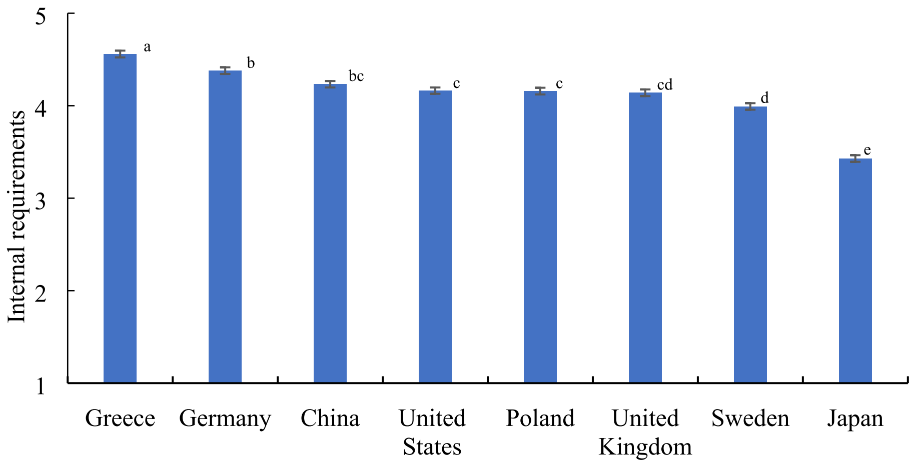

Fig. 4. Internal requirements by the country (ordered from highest to lowest estimated marginal means, with standard error bars). Means with different superscript letters over bars indicate significant difference ($p < 0.05$) between the countries.

the cross-country comparison of the factors with the second objective. Results revealed significant differences between countries in how all three factors of the TCS were rated. On average, the effects were medium, with External Affective Demands being the smallest and Functionality being the largest. Given the strong negative correlation between effect size and sample size (Kühberger et al., 2014), we can argue that the country differences across the three factors were robust. According to the country comparisons, participants from Greece reported the highest levels of external affective demands and internal demands, and also the lowest levels of functionality. In other words, participants from Greece were the ones who felt that their traffic system was the most stressful and the most poorly functioning, and that the system required more alertness from road users. Japan, Sweden, and the United Kingdom were the countries with the lowest levels of external affective demands and internal demands. These were the countries where participants perceived less need for vigilance and less stress from the traffic system. Gehlert et al. (2014) concluded that road users feel safer when the traffic system is perceived as more functional and less demanding. Countries such as Germany, Sweden, and the United Kingdom (with low external affective demands and high functionality) can be considered as countries where road users feel safer. This is not surprising, as national road safety statistics for these three countries reveal fewer fatalities, safer vehicles, and improved enforcement (WHO, 2023).

However, a number of questions remain, such as why the transport system in China is perceived as both demanding and functional. The differences between countries may be explained by geographical or planning differences, as the three countries where road users feel safest (Germany, Sweden, and the UK) are from regions with better road quality (World Economic Forum, 2019). When compared to other countries, China has the lowest urban population and the highest land area (World Data Bank, 2022; World Population Review, 2023). All of this could have an impact on infrastructure characteristics and, consequently, on travel behaviour and the perceived traffic climate of road users. Furthermore, Kaçan et al. (2019) also found that individual values affect the perception of the traffic climate. The differences in individual values across countries (Knafo et al., 2011) may explain some of the variations between countries in this study and is something which should be considered in future research.

The fourth objective of the study aimed to understand the effects of age, gender, and exposure to different traffic situations on the perceived traffic climate. Results showed that the effects of these variables were rather limited, with the factors explaining at most 11 % of the variance (mostly being around 4 % or lower). Similar to age-related changes in driving behaviours (e.g., de Winter & Dodou, 2010; Koppel et al., 2018), a significant age-related variation is also observed in participants' perceptions of the traffic climate. Increased age is associated with an increased perception of internal requirements and a decreased perception of external affective demands across different countries. In other words, older drivers perceived more skill requirements and less external stress. This lower level of external demands may be related to older drivers' increased confidence in their driving skills (Huang et al., 2020). At the same time, higher perceived internal requirements may be associated with increased concerns about their skills and other difficulties, such as visual abilities (Allen et al., 2019; Gruber et al., 2013). Age showed stronger relationships than gender. This may be a result of experiential effects, whereby road users' perceptions of traffic climate may change over time as they gain more experience and are exposed to different traffic situations. For example, Machado-León et al. (2016) found that driving experience significantly affects drivers' perceived crash risk in different situations. Increased exposure to diverse challenging traffic situations was associated with higher perceptions of external and internal demands and enhanced functionality in the United Kingdom, the United States, Germany, and Poland. While the results indicated some association between exposure and the perception of the traffic climate, they demonstrated only a limited relationship. It is important to note that, owing to the nature of the items utilised, the exposure factor encompasses only a limited aspect of drivers' driving experience. Consequently, this does not provide comprehensive information regarding the impact of exposure on the perception of the driver. With experience, participants' perceived demands from the external driving environment and the skills required to operate successfully in the traffic system may change.

In the majority of countries, age had a significant positive relationship with internal requirements (i.e. UK, US, Germany, Sweden,

Table 5
Effects of age, gender, and exposure to traffic situations on external affective demands.

Country	United Kingdom				United States				Germany				Sweden			
	R^2	$F(3, 949)$	β	p	R^2	$F(3, 1053)$	β	p	R^2	$F(3, 944)$	β	p	R^2	$F(3, 993)$	β	p
Overall model	0.06	20.73		<0.001	0.11	41.52		<0.001	0.07	23.46		<0.001	0.05	17.25		<0.001
Gender (1 = Male, 2 = Female)			−0.033	0.301			−0.011	0.702			0.019	0.543			−0.004	0.911
Age			−0.172	<0.001			−0.182	<0.001			−0.191	<0.001			−0.212	<0.001
Traffic situations			0.141	<0.001			0.217	<0.001			0.140	<0.001			0.038	0.240

Country	Poland				Greece				China				Japan			
	R^2	$F(3, 961)$	β	p	R^2	$F(3, 931)$	β	p	R^2	$F(3, 1049)$	β	p	R^2	$F(3, 965)$	β	p
Overall model	0.03	8.80		<0.001	0.03	8.59		<0.001	0.01	4.16		0.006	0.02	6.52		<0.001
Gender (1 = Male, 2 = Female)			0.021	0.517			0.028	0.403			−0.042	0.171			−0.008	0.802
Age			−0.058	0.075			−0.035	0.279			−0.015	0.628			−0.137	<0.001
Traffic situations			0.142	<0.001			0.160	<0.001			0.095	0.002			0.029	0.386

Table 6
Effects of age, gender, and exposure to traffic situations on functionality.

Country	United Kingdom				United States				Germany				Sweden			
	R^2	$F(3, 949)$	β	p	R^2	$F(3, 1053)$	β	p	R^2	$F(3, 944)$	β	p	R^2	$F(3, 993)$	β	p
Overall model	0.01	3.82		0.010	0.04	13.92		<0.001	0.02	7.87		<0.001	0.01	1.77		0.151
Gender (1 = Male, 2 = Female)			−0.020	0.543			−0.041	0.182			0.053	0.105			0.046	0.159
Age			0.063	0.056			0.075	0.018			0.092	0.006			0.060	0.063
Traffic situations			0.095	0.005			0.194	<0.001			0.153	<0.001			0.024	0.461

Country	Poland				Greece				China				Japan			
	R^2	$F(3, 961)$	β	p	R^2	$F(3, 931)$	β	p	R^2	$F(3, 1049)$	β	p	R^2	$F(3, 965)$	β	P
Overall model	0.02	5.81		<0.001	0.00	0.98		0.401	0.02	6.07		<0.001	0.04	12.21		<0.001
Gender (1 = Male, 2 = Female)			0.043	0.178			−0.026	0.432			0.033	0.282			0.015	0.646
Age			0.096	0.003			0.047	0.155			0.100	0.001			0.092	0.004
Traffic situations			0.111	<0.001			0.011	0.733			0.079	0.010			0.172	<0.001

Table 7
Effects of age, gender, and exposure to traffic situations on internal requirements.

Country	United Kingdom				United States				Germany				Sweden			
	R^2	*F(3, 949)*	*β*	*p*	R^2	*F(3, 1053)*	*β*	*p*	R^2	*F(3, 944)*	*β*	*p*	R^2	*F(3, 993)*	*β*	*p*
Overall model	0.05	14.87		<0.001	0.05	16.75		<0.001	0.04	12.86		<0.001	0.04	14.41		<0.001
Gender (1 = Male, 2 = Female)			−0.033	0.303			0.001	0.970			0.046	0.160			0.089	0.005
Age			0.201	<0.001			0.155	<0.001			0.202	<0.001			0.190	<0.001
Traffic situations			0.096	0.004			0.203	<0.001			0.078	0.020			0.041	0.207

Country	Poland				Greece				China				Japan			
	R^2	*F(3, 961)*	*β*	*p*	R^2	*F(3, 931)*	*β*	*p*	R^2	*F(3, 1049)*	*β*	*p*	R^2	*F(3, 965)*	*β*	*p*
Overall model	0.03	9.27		<0.001	0.03	7.83		<0.001	0.00	1.07		0.359	0.02	6.23		<0.001
Gender (1 = Male, 2 = Female)			0.051	0.114			0.083	0.013			0.005	0.860			−0.021	0.524
Age			0.129	<0.001			0.110	<0.001			−0.040	0.192			−0.118	<0.001
Traffic situations			0.134	<0.001			0.112	<0.001			0.037	0.226			0.061	0.066

Poland and Greece). However, an opposite relationship was found in Japan, where there was a negative relationship. The observed negative association may be a result of older drivers driving shorter distances and travelling more during day-time than younger drivers in Japan (Zhu et al., 2022). This phenomenon could potentially be attributed to relatively lower exposure to different traffic situations in Japan (Appendix C). Furthermore, when looking at the overall statistics, it can be concluded that Japan is one of the safest countries in terms of road safety (WHO, 2023; International Transport Forum, 2021), and a country with very high road quality (World Economic Forum, 2019). Consequently, older road users may not feel the need to maintain or improve their skills, as they are less often faced with challenging or demanding traffic situations. However, it should also be emphasized that this does not mean that older road users have a more objective perception of the traffic system, as their own perception may also be subject to biases. Overall, considering the limited effects of the three variables on perceived traffic climate, it can be concluded that perceived traffic climate is relatively free from demographic differences. Although it is still possible that increased exposure to particular traffic environments may impact road users' perceptions, the current results suggest that these perceptions are relatively stable across time and that road users evaluate their daily driving environment in the same way, regardless of their age or gender.

4.1. Limitations and future suggestions

A number of issues should be considered in terms of study limitations. First, in cross-cultural research, it is important to establish the reliability and validity of the measure across countries (or specific groups) in order to highlight differences across samples. In this regard, it is essential to examine the invariance of the measure across different groups of the sample (in this case, countries). Concerning this, mean differences between the countries should be treated with caution as full scalar invariance has not been established. As highlighted by a reviewer, it is necessary to acknowledge the significant intra-country variability for each country (see Appendix A). The cross-country comparisons are based solely on the means of the study sample. Consequently, there exist groups of drivers who perceive the traffic system as either highly demanding or less demanding in each country. While this observation may be attributed to numerous personal or environmental factors, it is crucial to recognise that further research is required to uncover intra-country differences in addition to age and gender. This is particularly important because the differences may be linked to inequalities in road safety, wherein drivers from marginalised areas or communities may experience more challenges and perceive their traffic system to be more demanding due to limited access to safe vehicles, infrastructure, or driver education.

In addition, the data were collected as part of a large project in which participants were recruited by an external company. While we aimed for a representative sample in terms of age, gender and geographical distribution in each country, the sample may not be representative of the population of each country with respect to the distribution of other socio-demographic variables such as education or income. Future studies could consider these variables to provide a more comprehensive assessment of the traffic climate for each country, together with consideration of other forms of exposure factors. Given the ideal sample size for measurement invariance per group (e.g., Meade, 2005) and the lack of relationship between sample size and achieving measurement invariance (Putnick & Bornstein, 2016), we believe having a high sample size per country strengthens the robustness of the findings for each country. Finally, the study is conducted with individuals who have a driving license. Whilst this guarantees that a certain minimum knowledge of traffic rules and exposure is to be expected, future studies could consider other groups of road users, such as children or other vulnerable road users, or conduct a comparison between drivers, cyclists, and pedestrians, in order to compare possible differences between road users in terms of their perception of the traffic climate. This would allow more robust conclusions about the traffic system of a particular country to be drawn. While taking into account differences between road users, consideration of the exposure factor per type of road user (e.g. distance travelled, daily walking time/distance, or infrastructure quality of the cycling environment) as potential moderators may provide further interaction effects to gain more qualitative insight.

5. Conclusions

In conclusion, the study examined the factorial structure and measurement invariance of the Traffic Climate Scale in eight countries and builds upon the existing literature utilising the TCS by examining the factorial structure of the scale with larger sample sizes and across eight countries exhibiting diverse road safety profiles. The results showed that the measurement showed factorial stability across different samples and that the scale can be used as a reliable measure across different countries, although the issues highlighted in the limitations section should not be ignored when interpreting the findings of the study and designing future research. The measurement invariance for the TCS was investigated for the first time in the literature. Furthermore, age, gender, and exposure to different traffic situations demonstrated a limited influence on perceptions of traffic climate. However, the effects also varied between countries. The findings of the study can be utilised to address challenges encountered by road users. Focusing on groups of road users perceiving more demand and less functionality and addressing antecedents for the differences in their perception could provide immediate action points for road safety researchers and policymakers. In light of the results, we encourage the use of the measurement to gather more profound information about road users' perceptions of the traffic system to deepen our understanding of road safety in different regions.

CRediT authorship contribution statement

İbrahim Öztürk: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Ruth Madigan:** Writing – review & editing, Methodology, Conceptualization. **Yee Mun Lee:** Writing – review & editing, Methodology, Conceptualization. **Elina Aittoniemi:** Writing – review & editing, Methodology, Conceptualization. **Esko Lehtonen:**

Writing – review & editing, Project administration, Methodology, Conceptualization. **Natasha Merat:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. . Frequency of exposure to each traffic situations.

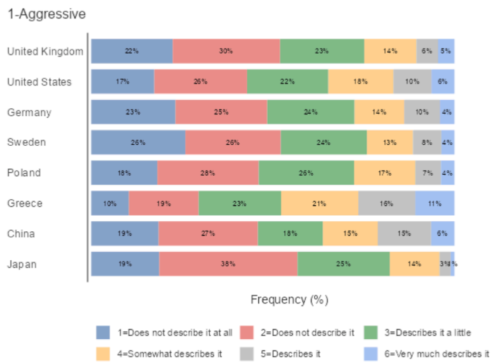
Traffic situations	Country	Mean	SD
1. Entering and exiting motorways via on– and off-ramps.	United Kingdom	2.506	1.257
	United States	3.183	1.317
	Germany	2.624	1.333
	Sweden	2.967	1.391
	Poland	2.686	1.351
	Greece	3.036	1.362
	China	2.904	1.159
	Japan	1.692	0.983
2. Driving in congested traffic	United Kingdom	3.146	1.286
	United States	3.144	1.311
	Germany	3.153	1.316
	Sweden	3.079	1.366
	Poland	3.732	1.198
	Greece	3.624	1.298
	China	3.721	0.949
	Japan	1.977	1.101
3. Driving in urban centres among pedestrians and cyclists	United Kingdom	3.294	1.282
	United States	3.029	1.410
	Germany	3.214	1.313
	Sweden	3.240	1.369
	Poland	3.782	1.215
	Greece	3.860	1.278
	China	3.723	0.980
	Japan	2.442	1.286
4. Parking in indoor parking lots	United Kingdom	2.415	1.291
	United States	2.360	1.402
	Germany	2.331	1.300
	Sweden	2.423	1.378
	Poland	2.719	1.372
	Greece	2.950	1.444
	China	3.857	1.047
	Japan	2.330	1.247
5. Driving through tunnels	United Kingdom	1.935	1.223
	United States	1.968	1.321
	Germany	2.224	1.321
	Sweden	2.260	1.373
	Poland	2.410	1.344
	Greece	2.353	1.313
	China	2.979	1.117
	Japan	1.896	1.099
6. Driving in intersections and roundabouts	United Kingdom	3.613	1.187
	United States	3.406	1.324
	Germany	3.690	1.272
	Sweden	3.596	1.343
	Poland	4.061	1.124
	Greece	3.804	1.243
	China	3.584	1.017
	Japan	2.356	1.391
7. Overtaking slower vehicles	United Kingdom	3.051	1.251

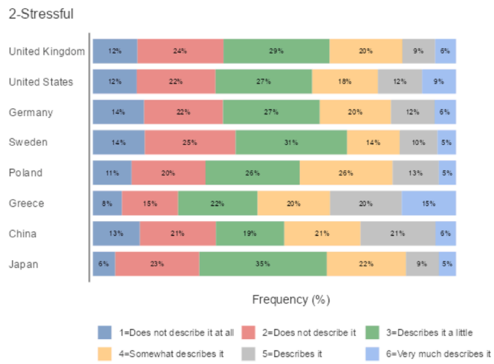
(*continued on next page*)

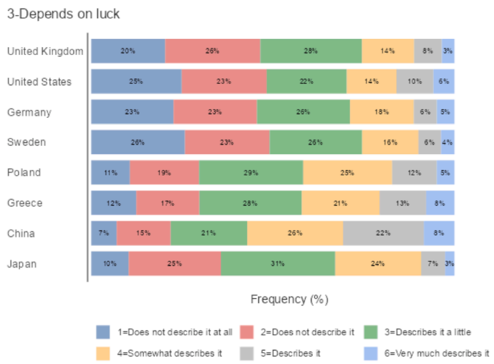
(*continued*)

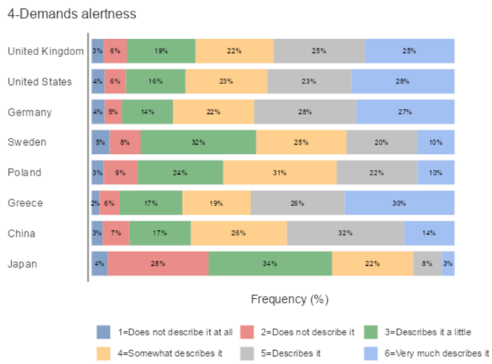
Traffic situations	Country	Mean	SD
	United States	3.329	1.307
	Germany	3.182	1.310
	Sweden	3.186	1.313
	Poland	3.782	1.176
	Greece	3.661	1.253
	China	3.675	1.027
	Japan	2.083	1.181
8. Driving in adverse weather conditions (rain, snow, fog)	United Kingdom	2.346	1.163
	United States	2.581	1.210
	Germany	2.700	1.183
	Sweden	2.476	1.167
	Poland	2.850	1.164
	Greece	2.400	1.244
	China	2.690	1.184
	Japan	2.157	1.136

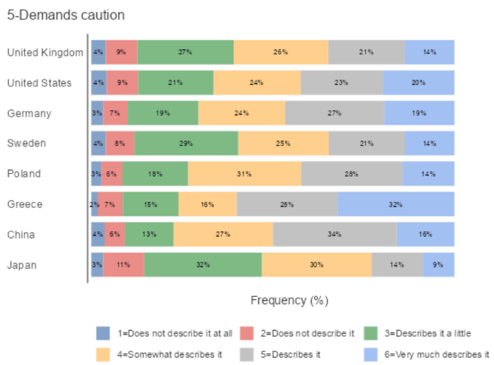
Appendix B. . Response distribution of 16 items of the TCS

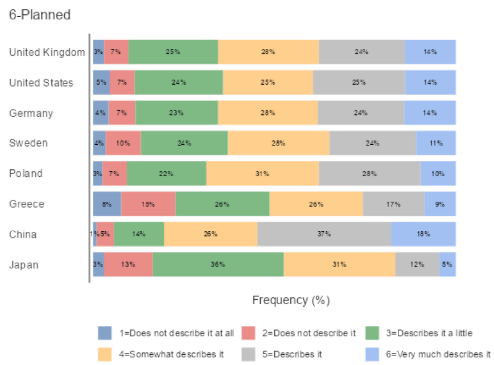


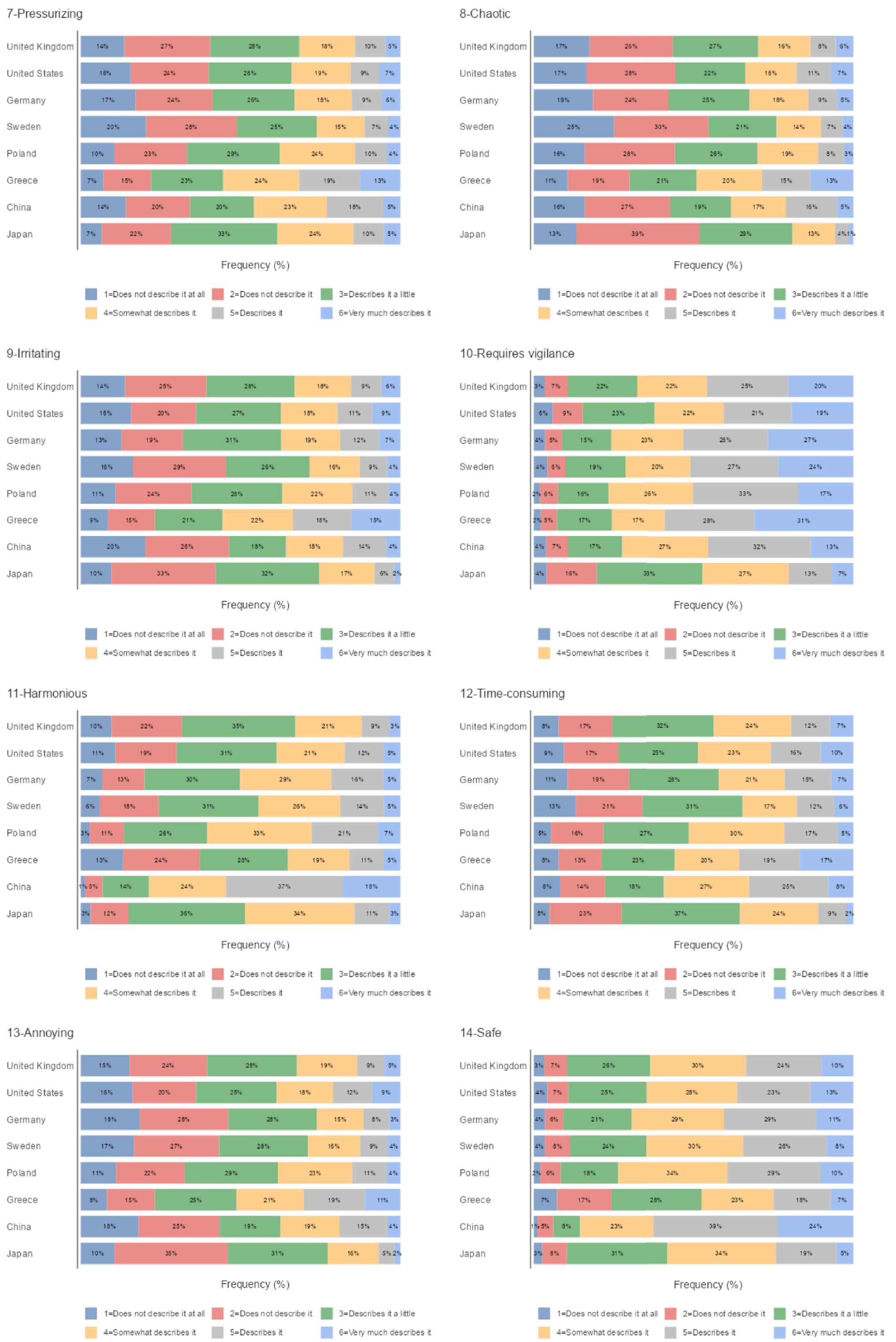


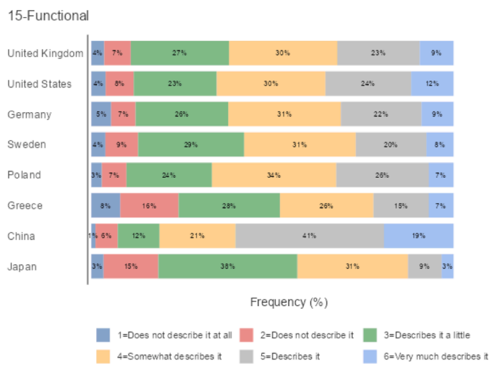


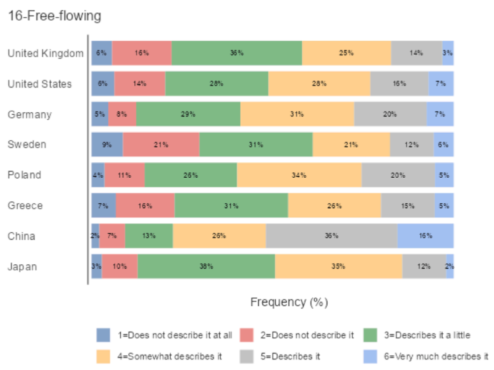







7-Pressurizing
8-Chaotic
9-Irritating
10-Requires vigilance
11-Harmonious
12-Time-consuming
13-Annoying
14-Safe
United Kingdom
United States
Germany
Sweden
Poland
Greece
China
Japan
Frequency (%)
1=Does not describe it at all
2=Does not describe it
3=Describes it a little
4=Somewhat describes it
5=Describes it
6=Very much describes it





Appendix C. . Correlations among variables per country

Country: United Kingdom

Variables		1	2	3	4	5
1. Age	*r*	–				
	p	–				
2. Traffic situations	*r*	−0.199	–			
	p	<0.001	–			
3. EAD	*r*	−0.199	0.182	–		
	p	<0.001	<0.001	–		
4. Fun	*r*	0.045	0.087	−0.105	–	
	p	0.164	0.007	0.001	–	
5. InRq	*r*	0.183	0.062	0.369	0.291	–
	p	<0.001	0.054	<0.001	<0.001	–

Country: United States

Variables		1	2	3	4	5
1. Age	*r*	–				
	p	–				
2. Traffic situations	*r*	−0.312	–			
	p	<0.001	–			
3. EAD	*r*	−0.250	0.275	–		
	p	<0.001	<0.001	–		
4. Fun	*r*	0.014	0.177	0.058	–	
	p	0.638	<0.001	0.058	–	
5. InRq	*r*	0.092	0.154	0.479	0.320	–
	p	0.003	<0.001	<0.001	<.001	–

Country: Germany

Variables		1	2	3	4	5
1. Age	*r*	–				
	p	–				
2. Traffic situations	*r*	−0.257	–			
	p	<0.001	–			
3. EAD	*r*	−0.227	0.185	–		
	p	<0.001	<0.001	–		
4. Fun	*r*	0.052	0.120	0.016	–	
	p	0.112	<0.001	0.630	–	
5. InRq	*r*	0.181	0.018	0.231	0.520	–
	p	<0.001	0.570	<0.001	<0.001	–

Country: Sweden

Variables		1	2	3	4	5
1. Age	*r*	–				
	p	–				
2. Traffic situations	*r*	−0.190	–			
	p	<0.001	–			
3. EAD	*r*	−0.219	0.079	–		
	p	<0.001	0.013	–		
4. Fun	*r*	0.056	0.003	−0.081	–	
	p	0.077	0.925	0.011	–	
5. InRq	*r*	0.184	−0.015	0.314	0.279	–
	p	<0.001	0.643	<0.001	<0.001	–

Country: Poland

Variables		1	2	3	4	5
1. Age	*r*	–				
	p	–				
2. Traffic situations	*r*	−0.205	–			
	p	<0.001	–			
3. EAD	*r*	−0.088	0.151	–		
	p	0.006	<0.001	–		
4. Fun	*r*	0.072	0.087	−0.045	–	
	p	0.026	0.007	0.164	–	
5. InRq	*r*	0.100	0.102	0.353	0.458	–
	p	0.002	0.002	<0.001	<0.001	–

Country: Greece

Variables		1	2	3	4	5
1. Age	*r*	–				
	p	–				
2. Traffic situations	*r*	−0.090	–			
	p	0.006	–			
3. EAD	*r*	−0.051	0.158	–		
	p	0.121	<0.001	–		
4. Fun	*r*	0.047	0.013	−0.306	–	
	p	0.152	0.699	<0.001	–	
5. InRq	*r*	0.096	0.085	0.594	−0.092	–
	p	0.003	0.009	<0.001	0.005	–

Country: China

Variables		1	2	3	4	5
1. Age	*r*	–				
	p	–				
2. Traffic situations	*r*	−0.021	–			
	p	0.506	–			
3. EAD	*r*	−0.020	0.098	–		
	p	0.521	0.001	–		
4. Fun	*r*	0.101	0.074	−0.079	–	

Country: Japan

Variables		1	2	3	4	5
1. Age	*r*	–				
	p	–				
2. Traffic situations	*r*	−0.015	–			
	p	0.641	–			
3. EAD	*r*	−0.137	0.033	–		
	p	<0.001	0.306	–		
4. Fun	*r*	0.090	0.167	0.089	–	

(continued on next page)

(*continued*)

Country: United Kingdom							Country: United States						
Variables		**1**	**2**	**3**	**4**	**5**	**Variables**		**1**	**2**	**3**	**4**	**5**
	p	0.001	0.016	0.010	–			*p*	0.005	<0.001	0.005	–	
5. InRq	*r*	−0.041	0.038	0.390	0.252	–	5. InRq	*r*	−0.119	0.068	0.602	0.310	–
	p	0.186	0.219	<0.001	<0.001	–		*p*	<0.001	0.034	<0.001	<0.001	–

Note. EAD: External Affective Demands, Fun: Functionality, InRq: Internal Requirements.

Data availability

Data will be available on reasonable request and made publicly available later following the grant agreement

References

Allen, H. K., Beck, K. H., & Zanjani, F. (2019). Driving concerns among older adults: Associations with driving skill, behaviors, and experiences. *Traffic Injury Prevention, 20*(1), 45–51. https://doi.org/10.1080/15389588.2018.1528358

Atombo, C., & Wu, C. (2022). Traffic safety climate factors in explaining driving behaviours and traffic crash involvement: Comparative study among male and female drivers. *Journal of Road Safety, 33*(1), 49–62. https://doi.org/10.3316/informit.370212838365494

Boer, D., Hanke, K., & He, J. (2018). On detecting systematic measurement error in cross-cultural research: A review and critical reflection on equivalence and invariance tests. *Journal of Cross-Cultural Psychology, 49*(5), 713–734. https://doi.org/10.1177/0022022117749042

Bogdan, S. R., Măirean, C., & Havârneanu, C. (2016). A meta-analysis of the association between anger and aggressive driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 42*, 350–364. https://doi.org/10.1016/j.trf.2016.05.009

Castro, C., Pablo Doncel, P., Ledesma, R. D., Montes, S. A., Daniela Barragan, D., Oviedo-Trespalacios, O., Bianchi, A., Kauer, N., Qu, W., & Padilla, J. (2024). Measurement invariance of the driving inattention scale (ARDES) across 7 countries. *Accident Analysis & Prevention, 195*, Article 107412. https://doi.org/10.1016/j.aap.2023.107412

Chen, F. F. (2007). Sensitivity of goodness of fit indexes to lack of measurement invariance. *Structural equation modeling: a multidisciplinary journal, 14*(3), 464–504. https://doi.org/10.1080/10705510701301834

Chu, W., Wu, C., Atombo, C., Zhang, H., & Özkan, T. (2019). Traffic climate, driver behaviour, and accidents involvement in China. *Accident Analysis & Prevention, 122*, 119–126. https://doi.org/10.1016/j.aap.2018.09.007

Cieciuch, J., & Davidov, E. (2015). Establishing measurement invariance across online and offline samples. A tutorial with the software packages Amos and Mplus. *Studia Psychologica: Theoria et. Praxis, 2*(15), 83–99.

Damjanović, M., Mićić, S., Matović, B., Jovanović, D., & Bulajić, A. (2022). Differences in Driving Anger among Professional Drivers: A Cross-Cultural Study. *International Journal of Environmental Research and Public Health, 19*(7), 4168. https://doi.org/10.3390/ijerph19074168

de Winter, J., & Dodou, D. (2010). The Driver Behaviour Questionnaire as a predictor of accidents: A meta-analysis. *Journal of Safety Research, 41*(6), 463–470. https://doi.org/10.1016/j.jsr.2010.10.007

Edwards, J., Freeman, J., Soole, D., & Watson, B. (2014). A framework for conceptualising traffic safety culture. *Transportation Research Part F: Traffic Psychology and Behaviour, 26*, 293–302. https://doi.org/10.1016/j.trf.2014.03.002

Furr, R. M. (2021). *Psychometrics: An introduction. SAGE.* publications.

Ge, Y., Qu, W., Qi, H., Cui, X., & Sun, X. (2020). Why people like using bikesharing: Factors influencing bikeshare use in a Chinese sample. *Transportation Research Part D: Transport and Environment, 87*, Article 102520. https://doi.org/10.1016/j.trd.2020.102520

Gehlert, T., Hagemeister, C., & Özkan, T. (2014). Traffic safety climate attitudes of road users in Germany. *Transportation Research Part F: Traffic Psychology and Behaviour, 26*, 326–336. https://doi.org/10.1016/j.trf.2013.12.011

Gruber, N., Mosimann, U. P., Müri, R. M., & Nef, T. (2013). Vision and night driving abilities of elderly drivers. *Traffic Injury Prevention, 14*(5), 477–485. https://doi.org/10.1080/15389588.2012.727510

Hoang, H., Bui, H. T., & Cools, M. (2025). Assessing the impact of traffic climate and risk-taking attitude on the risky riding behaviour of young motorcyclists in Vietnam. *Transportation Research Part F: Traffic Psychology and Behaviour, 109*, 336–353. https://doi.org/10.1016/j.trf.2024.12.019

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling: A multidisciplinary journal, 6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Huang, G., Luster, M., Karagol, I., Park, J. W., & Pitts, B. J. (2020). Self-perception of driving abilities in older age: A systematic review. *Transportation Research Part F: Traffic Psychology and Behaviour, 74*, 307–321. https://doi.org/10.1016/j.trf.2020.08.020

International Transport Forum (2021). Road safety report 2021 - Japan. https://www.itf-oecd.org/sites/default/files/japan-road-safety.pdf.

Jackson, D. L., Gillaspy, J. A., Jr., & Purc-Stephenson, R. (2009). Reporting practices in confirmatory factor analysis: An overview and some recommendations. *Psychological Methods, 14*(1), 6–23. https://doi.org/10.1037/a0014694

Jeong, S., & Lee, Y. (2019). Consequences of Not Conducting Measurement Invariance Tests in Cross-Cultural Studies: A Review of Current Research Practices and Recommendations. *Advances in Developing Human Resources, 21*(4), 466–483. https://doi.org/10.1177/1523422319870726

Kaçan Bibican, B. (2023). Traffic climate and motivation to drive safely: A cross cultural study (*Unpublished doctoral thesis*). https://open.metu.edu.tr/handle/11511/105988.

Kaçan, B., Fındık, G., Üzümcüoğlu, Y., Azık, D., Solmazer, G., Ersan, Ö., & Xheladini, G. (2019). Driver profiles based on values and traffic safety climate and their relationships with driver behaviors. *Transportation Research Part F: Traffic Psychology and Behaviour, 64*, 246–259. https://doi.org/10.1016/j.trf.2019.05.010

Knafo, A., Roccas, S., & Sagiv, L. (2011). The value of values in cross-cultural research: A special issue in honor of Shalom Schwartz. *Journal of Cross-Cultural Psychology, 42*(2), 178–185. https://doi.org/10.1177/0022022110396863

Koppel, S., Stephens, A., Charlton, J., Di Stefano, M., Darzins, P., Odell, M., & Marshall, S. (2018). The Driver Behaviour Questionnaire for older drivers: Do errors, violations and lapses change over time? *Accident Analysis & Prevention, 113*, 171–178. https://doi.org/10.1016/j.aap.2018.01.036

Kühberger, A., Fritz, A., & Scherndl, T. (2014). Publication Bias in Psychology: A Diagnosis Based on the Correlation between Effect Size and Sample Size. *PLOS ONE, 9*(9), Article e105825. https://doi.org/10.1371/journal.pone.0105825

Kummeneje, A., & Rundmo, T. (2020). Attitudes, risk perception and risk-taking behaviour among regular cyclists in Norway. *Transportation Research Part F: Traffic Psychology and Behaviour, 69*, 135–150. https://doi.org/10.1016/j.trf.2020.01.007

Lucidi, F., Girelli, L., Chirico, A., Alivernini, F., Cozzolino, M., Violani, C., & Mallia, L. (2019). Personality traits and attitudes toward traffic safety predict risky behavior across young, adult, and older drivers. *Frontiers in psychology, 10*, Article 442249. https://doi.org/10.3389/fpsyg.2019.00536

Machado-León, J. L., de Oña, J., de Oña, R., Eboli, L., & Mazzulla, G. (2016). Socio-economic and driving experience factors affecting drivers' perceptions of traffic crash risk. *Transportation research part F: traffic psychology and behaviour, 37*, 41–51. https://doi.org/10.1016/j.trf.2015.11.010

Mannocci, A., Saulle, R., Villari, P., & La Torre, G. (2019). Male gender, age and low income are risk factors for road traffic injuries among adolescents: An umbrella review of systematic reviews and meta-analyses. *Journal of Public Health, 27*, 263–272. https://doi.org/10.1007/s10389-018-0932-6

McIlroy, R. C., Nam, V. H., Bunyasi, B. W., Jikyong, U., Kokwaro, G. O., Wu, J., Hoque, M. S., Plant, K. L., Preston, J. M., & Stanton, N. A. (2020). Exploring the relationships between pedestrian behaviours and traffic safety attitudes in six countries. *Transportation Research Part F: Traffic Psychology and Behaviour, 68*, 257–271. https://doi.org/10.1016/j.trf.2019.11.006

Meade, A. W. (2005). Sample size and tests of measurement invariance. *Annual Conference of the Society for Industrial and Organizational Psychology*. Los Angeles, CA.

Moszoro, M., & Soto, M. (2022). Road quality and mean speed score. IMF Working Papers 2022/095 (Washington: International Monetary Fund).

Nævestad, T. O., & Milch, V. (2023). Traffic Safe Municipality: A Norwegian approval scheme to facilitate development of a municipal traffic safety culture.*Traffic Safety Research. An Interdisciplinary Journal, 5*, Article 000025.

Nævestad, T., Laiou, A., Phillips, R. O., Bjørnskau, T., & Yannis, G. (2019). Safety Culture among Private and Professional Drivers in Norway and Greece: Examining the Influence of National Road Safety Culture. *Safety, 5*(2), 20. https://doi.org/10.3390/safety5020020

Nævestad, T., Laiou, A., & Yannis, G. (2020). Safety Culture Among Car Drivers and Motorcycle Riders in Norway and Greece: Examining the Influence of Nationality, Region, and Transport Mode. *Frontiers in Sustainable Cities, 2*, Article 540891. https://doi.org/10.3389/frsc.2020.00023

Nguyen-Phuoc, D. Q., Oviedo-Trespalacios, O., Su, D. N., De Gruyter, C., & Nguyen, T. (2020). Mobile phone use among car drivers and motorcycle riders: The effect of problematic mobile phone use, attitudes, beliefs and perceived risk. *Accident Analysis & Prevention, 143*, Article 105592. https://doi.org/10.1016/j.aap.2020.105592

Nordfjærn, T., Jørgensen, S., & Rundmo, T. (2011). A cross-cultural comparison of road traffic risk perceptions, attitudes towards traffic safety and driver behaviour. *Journal of Risk Research, 14*(6), 657–684. https://doi.org/10.1080/13669877.2010.547259

Nordfjærn, T., Şimşekoğlu, Ö., & Rundmo, T. (2014). Culture related to road traffic safety: A comparison of eight countries using two conceptualizations of culture. *Accident Analysis & Prevention, 62*, 319–328. https://doi.org/10.1016/j.aap.2013.10.018

Oviedo-Trespalacios, O., Çelik, A. K., Marti-Belda, A., Włodarczyk, A., Demant, D., Nguyen-Phuoc, D. Q., Rubie, E., Oktay, E., Argandar, G. D., Rod, J., Natividade, J. C., Park, J., Bastos, J. T., Martínez-Buelvas, L., Pereira da Silva, M. D. F., Velindro, M., Sucha, M., Orozco-Fontalvo, M., Barboza-Palomino, M., & King, M. (2021). Alcohol-impaired Walking in 16 Countries: A Theory-Based Investigation. *Accident Analysis & Prevention, 159*, Article 106212. https://doi.org/10.1016/j.aap.2021.106212

Özkan, T., & Lajunen, T. (unpublished). *Traffic climate scale*.

Özkan, T., & Lajunen, T. (2011). *Person and environment: Traffic culture. In Handbook of Traffic Psychology* (pp. 179–192). Academic Press.

Özkan, T., & Lajunen, T. (2015). A_General_Traffic_Safety_Culture_System_G-TraSaCu-S. *TraSaCu Project, Deliverable, D2*, 1. https://www.researchgate.net/publication/319241963_A_General_Traffic_Safety_Culture_System_G-TraSaCu-S.

Öztürk, İ., Wallén Warner, H., & Özkan, T. (2022). Traffic climate scale: Comparing samples from Turkey and Sweden. *IATSS Research, 46*(1), 130–137. https://doi.org/10.1016/j.iatssr.2021.11.001

Öztürk, İ., Wallén Warner, H., & Özkan, T. (2023). Automation preferences by traffic climate and driver skills in two samples from countries with different levels of traffic safety. *Transportation Research Record: Journal of the Transportation Research Board, 2677*(2), 1701–1712. https://doi.org/10.1177/03611981221109593

Öztürk, İ., Tümer, E., & Öz, B. (2024). Exploring the relationship between traffic resilience and driver behaviors through traffic climate. *Traffic Safety Research, 6*, 1–13. https://doi.org/10.55329/trjs3850

Putnick, D. L., & Bornstein, M. H. (2016). Measurement invariance conventions and reporting: The state of the art and future directions for psychological research. *Developmental Review, 41*, 71–90. https://doi.org/10.1016/j.dr.2016.06.004

Qu, W., Xu, J., Ge, Y., Sun, X., & Zhang, K. (2019). Development and validation of a questionnaire to assess public receptivity toward autonomous vehicles and its relation with the traffic safety climate in China. *Accident Analysis & Prevention, 128*, 78–86. https://doi.org/10.1016/j.aap.2019.04.006

Revilla, M., & Höhne, J. K. (2020). How long do respondents think online surveys should be? New evidence from two online panels in Germany. *International Journal of Market Research.*. https://doi.org/10.1177/1470785320943049

Russell, D. W. (2002). In search of underlying dimensions: The use (and abuse) of factor analysis in Personality and Social Psychology Bulletin. *Personality and social psychology bulletin, 28*(12), 1629–1646. https://doi.org/10.1177/014616702237645

Rutkowski, L., & Svetina, D. (2014). Assessing the hypothesis of measurement invariance in the context of large-scale international surveys. *Educational and Psychological Measurement, 74*(1), 31–57. https://doi.org/10.1177/0013164413498257

Schermelleh-Engel, K., Moosbrugger, H., & Müller, H. (2003). Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. *Methods of psychological research online, 8*(2), 23–74.

Schmitt, N., & Kuljanin, G. (2008). Measurement invariance: Review of practice and implications. *Human Resource Management Review, 18*(4), 210–222. https://doi.org/10.1016/j.hrmr.2008.03.003

Stephens, A. N., Crotty, R., Trawley, S., & Oxley, J. (2024). Multigroup invariance of measure for angry drivers (MAD) scale using a representative sample of drivers in Australia. *Journal of Safety Research, 90*, 208–215. https://doi.org/10.1016/j.jsr.2024.05.014

Stipdonk, H., Aarts, L., Campsall, D., Carnis, L., Feypell, V., Fosdick, T., Shelton, D., Small, M., & Vadeby, A. (2024). Maturity measurement in road traffic injury prevention. *Traffic Safety Research, 8*, Article e000045. https://doi.org/10.55329/uvfc1655

Üzümcüoğlu, Y., & Özkan, T. (2019). Traffic climate and driver behaviors: Explicit and implicit measures. *Transportation research part F: Traffic psychology and behaviour, 62*, 805–818. https://doi.org/10.1016/j.trf.2019.03.016

Üzümcüoğlu, Y., Özkan, T., Wu, C., & Zhang, H. (2019). How drivers perceive traffic? How they behave in traffic of Turkey and China? *Transportation research part F: traffic psychology and behaviour, 64*, 463–471. https://doi.org/10.1016/j.trf.2019.06.006

Üzümcüoğlu, Y., Ersan, Ö., Kaçan, B., Solmazer, G., Azık, D., Fındık, G., Özkan, T., Lajunen, T., Öz, B., Pashkevich, A., Pashkevich, M., Danelli-Mylona, V., Georgogianni, D., Berisha, K. E., Makris, E., Shubenkova, K., & Xheladini, G. (2020). A short scale of traffic climate across five countries. *Mustafa Kemal Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 17*(46), 673–702.

Van de Schoot, R., Lugtig, P., & Hox, J. (2012). A checklist for testing measurement invariance. *European journal of developmental psychology, 9*(4), 486–492. https://doi.org/10.1080/17405629.2012.686740

Van De Schoot, R., Schmidt, P., De Beuckelaer, A., Lek, K., & Zondervan-Zwijnenburg, M. (2015). Measurement invariance. *Frontiers in Psychology, 6*, Article 152747. https://doi.org/10.3389/fpsyg.2015.01064

Wallén Warner, H., Özkan, T., & Lajunen, T. (2009). Cross-cultural differences in drivers' speed choice. *Accident Analysis & Prevention, 41*(4), 816–819. https://doi.org/10.1016/j.aap.2009.04.004

World Data Bank (2022). Urban population (% of total population). https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS.

World Economic Forum (2019). Roads quality - Country rankings. https://www.theglobaleconomy.com/rankings/roads_quality/.

World Health Organisation (2018). Global status report on road safety 2018. https://www.who.int/publications/i/item/9789241565684.

World Health Organisation (2023). Global status report on road safety 2023. https://www.who.int/publications/i/item/9789240086517.

World Health Organization (2023). Global status report on road safety 2023. who.int/publications/i/item/9789240086517.

World Population Review (2023). World population by country 2023 (Live). https://worldpopulationreview.com/#top.

Yannis, G., Nikolaou, D., Laiou, A., Stürmer, Y. A., Buttler, I., & Jankowska-Karpa, D. (2020). Vulnerable road users: Cross-cultural perspectives on performance and attitudes. *IATSS Research, 44*(3), 220–229. https://doi.org/10.1016/j.iatssr.2020.08.006

Zhang, Q., Ge, Y., Qu, W., Zhang, K., & Sun, X. (2018). The traffic climate in China: The mediating effect of traffic safety climate between personality and dangerous driving behavior. *Accident Analysis & Prevention, 113*, 213–223. https://doi.org/10.1016/j.aap.2018.01.031

Zhu, Y., Jiang, M., & Yamamoto, T. (2022). Analysis on the driving behavior of old drivers by driving recorder GPS trajectory data. *Asian Transport Studies, 8*, Article 100063. https://doi.org/10.1016/j.eastsj.2022.100063