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Short communication

Ergonomic principles of road signs comprehension: A literature review

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ABSTRACT

Road signs are an essential component of a safe driving environment. Understanding road signs is vital to road safety. This paper reviews many earlier investigations into how well drivers understand road signs, considering ergonomic principles. Articles from 2012 to 2023, indexed by Web of Science, Scopus, Google Scholar, IEEE, Semantic Scholar, Science Direct, Cambridge Core, and JSTOR, were used to evaluate the literature on ergonomics and road signs comprehension. The analysis reveals that some evaluation techniques have been created to measure how well road signs are understood. Based on International Standard Organization (ISO, 3846 and 39001), 268 road signs were reviewed out of which, 112 (41.79 %) road signs are associated with lower comprehension scores and may pose a higher risk to road users who many not fully understand their meaning. 156 (58.21 %) road signs associated with higher comprehension scores and likely understood by road users. In conclusion, human traits, cognitive sign design and ergonomic principles are crucial for understanding and producing road signs. It was suggested that applying ergonomic ideas to the design of road signs can increase user comprehension.

1. Introduction

Ergonomic problems exist in numerous aspects of life; one such aspect is transportation, specifically the road. However, during the transportation of goods and services from origin to destination, unavoidable consequences result in the loss of lives, body parts and properties, known as road accidents (Mustapha et al., 2022). Studies have shown that the rate of these road accidents is relatively high, which is caused because of mechanical, environmental, and human factors. The human factor constitutes about 90 % of road accidents (Zarei et al., 2019). Per this percentage, drivers' action or reaction makes up 90 % (Idris & Mustapha, 2019). Drivers as road users are critical factors in road safety performance. Studies have shown that a critical contributing factor to road traffic accidents in Nigeria is the driver's attitude to driving codes and etiquette (Anene, 2022). Human errors can occur due to various factors, such as driver errors. They can also be caused by the failure of work systems and drivers to interact with each other effectively. Several road accidents occur because of the driver's nonchalant attitude when driving. Such attitude includes, among others, sleepiness, driving under the influence of drugs and/or alcohol, fatigue, faulty preparation, and ignorance of highway codes and road signs (Idris & Mustapha, 2019).

Road signs are instruments used to regulate road users' behaviour and the traffic flow using symbols, colours, and text (Idris &

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Mustapha, 2019). When the road signs are correctly followed, the risk and rate of road accidents are reduced (Ishartomo et al., 2020). The degree to which road signs lessen the occurrence and frequency of road accidents is determined by several factors, including the type and location of the sign and driver behaviour. Driver education, traffic law enforcement, and road and highway design are critical components. Even though scholars have long shown that road signs notably impact transport safety. For example, a World Health Organization (WHO) study discovered that road signs can reduce the risk of accidents by up to 30 % (WHO, 2023).

Similarly, the National Highway Traffic Safety Administration discovered that putting up speed limit signs can reduce speeding-related accidents by up to 20 % (Hallmark et al., 2015). Moreover, installing stop signs can result in a 40 % reduction in rear-end collisions, according to the Insurance Institute for Highway Safety (Martínez-Ruíz et al., 2019). The International Road Federation (IRF) conducted a study in the United Kingdom that discovered a 41 % reduction in the incidence of road accidents following the mounting of road signs (Sirajudeen et al., 2022). Boelhouwer et al., (2019) further examined one of the most impactful road signs for notifying motorists regarding potential dangers like speed bumps, sharp curves, and pedestrian crossings. Agyapong & Ojo, (2018) discovered that erecting road signs like speed limit, stop, and yield signs helped improve road safety and reduce accidents by pedestrians and cyclists. There is a plethora of empirical findings that support the idea that road signs increase safety. Many drivers acknowledged that paying full attention to road signs helped them avoid accidents (Beanland et al., 2013). Law enforcement authorities frequently stress the importance of road signs in guaranteeing road safety (Woods, 2021). These proofs highly recommend that road signs substantially impact road safety. Notwithstanding, it is critical to recognise that road signs are not an antidote; they should therefore be construed as one aspect of a robust road safety strategic approach. The failure of law enforcers and agencies to enforce road rules is often the cause of violations of road signs.

This paper aims to review the various studies conducted on driver comprehension of traffic signs. It also explores the principles of ergonomics related to this issue. This can be cultivated by considering people's mental development and reactions to the system used. The Human Information Processing (HIP) model is best suited for the review paper because it provides a framework for understanding

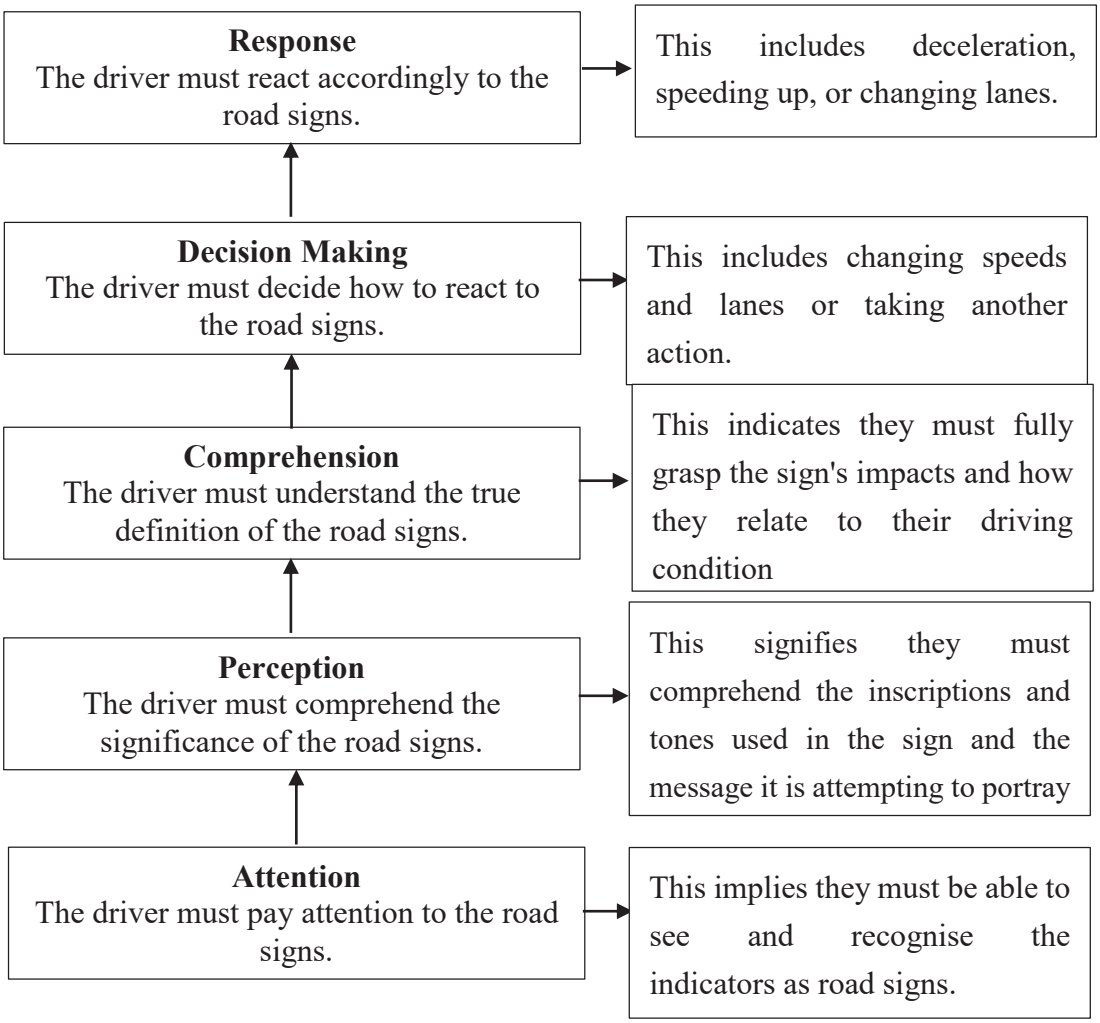

Fig. 1. HIP model of knowledge acquisition procedures.

how motorists handle and perceive road signs and identifying factors that can influence road sign comprehension. The HIP model defines a sequence of phases and predict response times, error types and rate with environmental stimuli and other aspects of human performance (Mayhorn & Wogalter, 2010). For instance, the model focuses on factors such as sign size, contrast, and message complexity that affect how well drivers understand road signs. Human Information Processing (HIP) studies the intricate association of the mental work processes of humans with a working system (Hutchins, 2020).

Furthermore, the dimensions, restrictions, and mental work characteristics can be understood through the familiarity of the HIP in designing ideal connections. Visual display design, training methods, operating procedures, and the technique of delivering information must be accessed through the HIP to understand road signs correctly. Modelling how the human brain utilises information is one method to understand the human–machine interface (Richards et al., 2022). The HIP model divides the knowledge acquisition procedures into five levels, as shown in Fig. 1:

Physical stimuli generate nerve activity that is either processed or not. The cognitive processes include decision-making and perception and are supported by storing information. The process of perception is the amalgamation of stimulus felt by the human sense“ linked to experience and knowledge to give meaning to the stimulus obtained. Implementing the chosen decision is the next stage of the HIP model. Process efficacy is incomplete by resource consideration. This confirms the dimensions of mental developments humans can carry out to produce feedback and stimuli from the environment, which humans then sense once more, as shown in Fig. 2. Drivers must look into and revise challenging signals to understand (Xing et al., 2019). Road accidents frequently include human error and confusion with warning signs. This review paper examined the ergonomics of traffic sign comprehension.

The authors of the review paper use the HIP model to analyse the prior work on road sign comprehension. The authors also use the HIP model to identify relevant gaps and future research directions. The HIP model is useful for determining how drivers handle and comprehend road signs. It can enhance road sign design and reduce the risk of traffic accidents.

1.1. Purpose and scope of literature review

1.1.1. Purpose of literature review

The purpose of this literature review is to evaluate and summarise existing research on the ergonomic principles of road sign comprehension. The review attempts to provide a thorough knowledge of the elements impacting road sign interpretation by considering studies from several nations, various types of road signs, and a wide range of study methods. This all-encompassing approach is vital for shaping the optimisation of road sign designs and legislation that can improve worldwide road safety and traffic management.

1.1.2. Scope of literature review

The scope of the literature review is as follows:

1. **Country:** The literature review includes studies and research from all across the world. It offers a thorough examination of traffic sign comprehension studies to have a worldwide view on the topic. This technique ensures that varied road conditions, sign designs, and driving cultures are considered, which is critical for creating comprehensive insights regarding road sign ergonomics.
2. **Road signs:** The study focused on prohibitive, warning, and guidance signs, which are the three basic types of traffic signs used worldwide. These signs communicate directions, notify of possible dangers, and give drivers appropriate assistance and information.

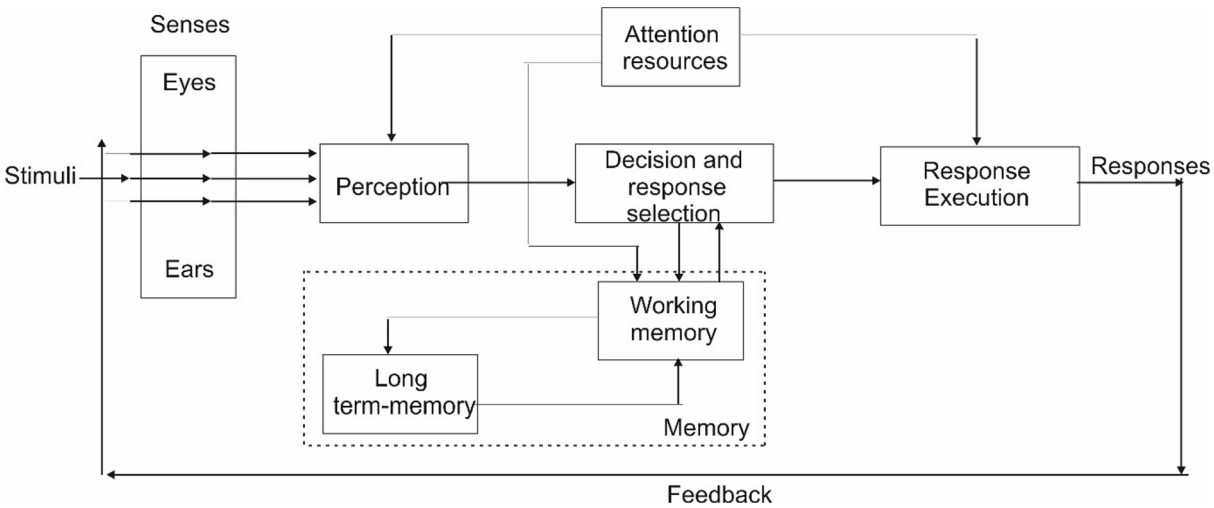

Fig. 2. HIP Model.

3. **Methods used:** The review assesses papers that used several research approaches, such as quantitative surveys, eye-tracking tests, cognitive psychology assessments, and field observations. This multifaceted research strategy enables a full evaluation of road sign comprehension from multiple perspectives, considering both objective performance measurements and cognitive processes.

2. Studies on road signs comprehension

The drivers' awareness level provides insight into the effectiveness of road signs. Low awareness levels will result in less memory for storing the importance of signs and the benefits of a fast response time for the driver (Oviedo-Trespalacios et al., 2019). Fuzzy and vague road signs may lead a driver to make an error and indulge in unsafe behaviour. The meaning of a road sign can be lowered by misinterpretation, which may be the leading cause of road accidents (Akple et al., 2020). According to International Standardization Organization (ISO) 3846, signs are considered suitable when they pass a comprehension test with at least a 67 per cent accuracy rate (Siuhi et al., 2021). The American National Standard Institute (ANSI) offers a somewhat different criterion that uses an accuracy of comprehension rating of 85 per cent (Siuhi et al., 2021). Based on these standards, numerous studies have revealed that failure to comprehend traffic signs is a serious issue in many nations. Table 1 summarises prior studies on road signs from 2012 to 2023.

Kirmizioglu & Tuydes-Yaman, (2012) investigated how well-understood 39 traffic signals were by urban drivers in Ankara, Turkey. Age, average annual kilometres travelled in cities, driving licence class, educational background, gender, number of traffic infractions received in the previous five years, occupation, required occupational driving and years of experience are some of the features of the drivers in this study. The traffic signs were divided into five groups according to their level of comprehension. The findings revealed that the drivers correctly recognised 30.76 % of the road signs and recommended using media campaigns for road safety and educational programmes for driving instruction.

Ou & Liu (2012) assessed the impact of training and elements of traffic signs on understanding 65 signs in Taiwan by 50 road users in Taiwan and Vietnam, respectively. Three training scenarios (earlier, instantly succeeding, and subsequently a month after training) based on five ergonomic design standards (familiarity, concreteness, simplicity, meaningfulness, and semantic closeness) were used in the study. According to the results, users from diverse cultural or linguistic backgrounds understood traffic signs differently.

Shinar & Vogelzang (2013) evaluated the advantages of text and symbolic traffic signs regarding familiarity, comprehensibility, and reaction speed. The thirty new symbolic signs in this test had text added to them. Traffic signs were displayed to drivers in symbols, text, and a combination of symbols with text. The results indicated that adding words to symbols could increase understanding of unknown signs' accuracy and quicken comprehension.

Setiadji and Sodikin (2016) contended that using road signs could be prejudiced by design and non-design factors by a group of Indonesian drivers. Fifteen traffic signs were used to attain a level of intelligibility. Driver's features, namely length of driving license ownership, age, educational background, gender, occupation, type of driver's license and driving performance, were used to obtain demographic features of the drivers. It was later revealed that 33 % of those questioned could not recognise the connotation of the signs. The driver's understanding of road signs significantly impacts the type of driver's license.

Brucal et al. (2015) assessed the understanding of twenty regulated traffic signs. They proposed that traffic signs' effectiveness may depend on the design and non-design factors. Driving ability and traffic sign comprehension are related to non-design factors. The study focused on the new sign's compatibility with its surroundings. Contrarily, conceptual compatibility and physical representation are concentrated on the actual icon or words on traffic signs. The best alternate design for updating traffic signs was selected while considering ergonomic considerations using Kepner-Tregoe Decision Analysis (KTDA). A group of drivers from Indonesia rate the legibility of fifteen traffic signs. The drivers' age, driving distance, educational background, gender, kind of licence, length of licence tenure and occupation were all covered in this study. Sixty-seven per cent of the respondents grasped the significance of the signals. Traffic signs were known to be better understood by commercial drivers than by personal drivers. The kind of driver's licence significantly impacted the driver's comprehension exam with a strong correlation to the driver's occupation.

Shinar & Vogelzang (2013) studied sign redesign's spatial compatibility in the placement of the information. Three modified designs were developed and tested for each sign using the ergonomic principles of physical representation, conceptual compatibility, and space compatibility (Berrio et al., 2022). Contrarily, physical and conceptual representations accent the words or representation of traffic signals. Also used to make decisions was Kepner-Tregoe Decision Analysis (KTDA).

28 Israeli symbolic traffic signs were presented to 50 undergraduate students from Ben-Gurion University Israel. The results were compared by Ben-Bassat & Shinar (2018). The experiment focuses on the meaning of signs and response time precision. Data analysis shows that younger drivers (ages 23 to 30) outperformed older drivers (ages 65 to 91) in precision and reaction time. The presenting condition did not impact either set of drivers' ability to understand the signage (with or without context). However, the context presentation extended the time needed to understand the indicators. For both groups of drivers, the presentation of the background made it take longer to comprehend the indications. However, it took more time to comprehend the indications because of the context presentation. This investigation will assist in retraining elderly motorists in signs understanding by considering the traffic circumstances closely comparable to the prevailing situation.

The re-usability of 21 signs using 57 inactive Hongkong Chinese drivers who held valid licences while considering the drivers' characteristics and mental sign features was investigated by Ng & Chan (2016). The mental design characteristics of the components in this study are recognizability, conciseness, elegance, and significance. The drivers ranked the significance of each element designed on a measure of 0 to 100. The subjects were also required to answer multiple-choice questions about interpretations of the signage. Participants in this study who had not driven in a year and those who had never driven after getting their licence performed equally well in re-usability. Nevertheless, suitable signage units can allow drivers to utilise the signs. This guideline might benefit signage design professionals who think clearly defined elements make the signs easy to identify.

Table 1
An overview of the 20 studies reviewed.

Author(s) (Year)	Respondents	Road signs	Demographic features	Area	Methods	Findings	Gap/ Limitations
Robielos & Lin, (2022)	60 Filipinos	73 road signs	Not described	Complexity, familiarity, semantic distance, and concreteness of design elements	Matching-based comprehension exam	According to the findings, many traffic signs studied in the Philippines did not fulfil the comprehension benchmark.	1. The study does not evaluate respondents' demography, such as age, gender and academic qualifications, which might impact traffic sign comprehension. 2. The respondents limit the findings' generalisation to a larger number of people.
Hou & Yang (2021)	60 participants	24 Traffic signs	Not described	Traffic sign comprehension	An experiment on the recognition of signs was conducted in a laboratory setting.	1. The research presents neurological proof that ERPs are a trustable way of detecting traffic sign comprehension. 2. The research spotlighted the neural mechanisms in people's understanding of sign connotations. 3. Reductions in the N300 and N400 elements were noted, denoting that comprehension of traffic signs aids in reducing coherent and conceptual discrepancies in both signs and their meant definitions.	1. The study was conducted under close monitoring, although it is crucial to highlight that real-life conditions are more intricate. 2. The ERP technique required at least sign-word matching performances to affirm mastery. 3. Connecting the electrode cap ended up taking about 10–15 m. 4. The study does not evaluate respondents' demography, such as age, gender and academic qualifications, which might impact traffic sign comprehension.
Dewi et al. (2019)	79 Motorbike riders	Warning signs	Age	Traffic sign comprehension	Experimental	Participants prove unsatisfactory comprehension of safety procedures, such as the relevance of checking vehicular machinery and acting responsibly on the road.	1. The lack of a national curriculum on traffic ethics education is the study's major limitation, as it impedes thorough adherence to road safety education. 2. Insufficient effective teaching and family involvement in restricting kids from motorcycling without required permits add value to the restriction.
Ben-Bassat et al., (2019)	27 Ergonomics experts	31 roads signs	Not described	Compatibility, familiarity, and standardisation of road signs	Experimental	1. Compared to regular signs of the same connotation, the alternative designs got substantially higher evaluations in ergonomics design. 2. Prior studies established a strong link between professional evaluations and word recognition information.	1. There was a small sample size, and the experimental research design was not completely acknowledged. 2. It was impossible to evaluate all conventional signs. A decision had to be made about which signage would be evaluated.

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Table 1 (*continued*)

Author(s) (Year)	Respondents	Road signs	Demographic features	Area	Methods	Findings	Gap/ Limitations
							3. The study does not evaluate respondents' demography, such as age, gender and academic qualifications, which might impact traffic sign comprehension.
Ben-Bassat, (2019)	Israeli drivers	63 road signs	Not described	Comprehension and learnability	Experimental in the form of pen and paper questionnaire	The research results highlight the significance of ergonomic design in influencing the comprehensibility and ease of understanding of road signs.	1. The study's findings emphasise ergonomic design's importance in influencing road signs' coherency and learnability. 2. The methodology was limited to a single past study, which could imply the research results' comprehensiveness. 3. The dearth of an extended recall experiment limits observations into the comprehensibility of road signs for groups of users, such as tourists and new drivers. 4. The study does not evaluate respondents' demography, such as age, gender and academic qualifications, which might impact traffic sign comprehension.
Ben-Bassat & Shinar, (2018)	140 Ben-Gurion University of Israel engineering	12 warning signs	Not described	Comprehensibility of sign variations	Computer-based questionnaire	Sign characteristics associated with the symbol have a major effect on cognition.	1. The study was conducted on a small group of university students and standardising the result needs adequate care. 2. The study does not evaluate respondents' demography, such as age, gender, and academic qualifications, which might impact traffic sign comprehension.
Bañares et al., (2018)	90 licensed drivers in the Philippines	40 road warning signs	Not described	Comprehensibility and redesign	Pre-comprehension assessment with four categories for responses; comprehension assessment with five ergonomic principles for first-stage low comprehension levels using scaled numerical responses to create three redesigned alternative signs; Using the Analytical Hierarchy Process, five	Less than half of the signs evaluated met the ANSI comprehension baselines.	1. The paper has not addressed all critical factors affecting road warning signs, such as glance legibility, conspicuity, and learnability. Legibility distance and reaction time. 2. The study does not evaluate respondents' demography, such as age, gender and academic qualifications, which might impact traffic sign comprehension.

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Table 1 (*continued*)

Author(s) (Year)	Respondents	Road signs	Demographic features	Area	Methods	Findings	Gap/ Limitations
					experts evaluate the suitability of three redesigned alternative signage (AHP)		
Ghadban et al., (2018)	402 drivers at Qatar University	7 road signs	Nationality, language, gender, educational level age,	Comprehensibility	Online multiple-choice questionnaire	1. Drivers comprehended 80.9 per cent of traffic signs. 2. Notwithstanding their straightforwardness and genericness, approximately 20 % of drivers did not respond properly to at least one sign. 3. Male drivers had a better grasp than females. However, female drivers had reduced crash statistics due to reduced mileage and representation.	1. The research focused on a subset of traffic signs. It will not truly reflect the readability of all road signs in Qatar. 2. The study did not investigate probable disparity among drivers with varying driving experience or education levels, which could have yielded useful information.
Taamneh & Alkheder, (2018)	400 Jordanian drivers	39 (15 regulatory signs, 17 warning signs, seven guidance signs)	Number of traffic violations, monthly income, driving license category, marital status, gender, experience, educational background & age	Familiarity and comprehensibility	Paper-based questionnaire	1. Jordanian drivers were more acquainted with traffic signs than they were comprehensible. 2. Respondents with a commercial driver's licence demonstrated greater recognition and comprehension than those with a regular licence. 3. The rate of road infringements did not affect the knowledge and comprehension of road signs. 4. Drivers with more than 11 years of experience were more acquainted with and understood road signs than those with less than two years of experience.	1. The study only included Jordanian drivers, limiting the study results' applicability to other countries. 2. The analysis did not consider other factors influencing familiarity and comprehension, such as education level or cultural background. 3. The study did not look into the effect of roadways or visibility on drivers' understanding of road signs.
Choocharukul & Sriroon gvikrai (2017)	1091 foreign tourists visiting Thailand	25 traffic signs	Driving experience in a foreign country within the last three years, nationality, driving license ownership, age, and gender	Comprehensibility, road safety awareness	Open-ended questionnaire	1. Tourists partially understood local road signs, particularly text-based signs such as stop signs and yield signs, which tested their comprehension. 2. Several sociodemographic variables, such as age, driver's licence possession, driving experience in overseas nations, and national origin, substantially influenced customers' regarding traffic sign understanding.	1. The study concentrated on foreign visitors touring Thailand, confining the study results' applicability to other areas. 2. The study did not investigate other factors influencing tourist knowledge and understanding of traffic signs, such as linguistic competence or interaction with driving guidelines.

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Table 1 (*continued*)

Author(s) (Year)	Respondents	Road signs	Demographic features	Area	Methods	Findings	Gap/ Limitations
							3. The investigation did not examine tourists' exact driver habits or observance of regional road rules.
Ng & Chan (2016)	57 inactive Chinese drivers from Hong Kong (not driving for at least a year)	21 road signs	Gender, driving test experience, driving license ownership & age	Re-usability	Multiple-choice survey conducted on paper.	1. Respondents who had not driven for at least one year performed similarly to those with no on-road driving experience when acquiring their licence. 2. Road signs were more reusable when acquainted, unreinforced, simple, and relevant.	1. The study did not analyse active drivers' comprehension abilities; thus, the outcomes may not completely reflect the total number of motorists. 2. The study mainly concentrated on the design features of road signs. 3. External factors such as roadways or driver behaviour were not taken into account in the study.
Setiadji & Sodikin (2016)	202 Indonesian drivers	15 road signs (5 each: warning, regulator, and command signs)	Type of driving license, occupation, mileage, gender, educational background, duration of driving license ownership & age	Comprehensibility	Paper-based questionnaire	1. The comprehension rate of road signs was found to be 67 per cent among 202 people surveyed in the Soloraya area of Central Java Province, which is significantly greater than the understanding rates in prior research in Dhaka, Bangladesh, and desert areas (Kuwait, Oman, Qatar, UAE, and Bahrain). 2. The type of driver's licence held substantially impacted the drivers' understanding of traffic signs. Those who held B2 and B2 Public licences and B1 and B1 Public licences demonstrated more awareness than those who held C, A, and A public licences 3. There was a high correlation between licence type and occupation, with truck, bus, and taxi drivers who held B2 and B2 Public or B1 and B1 Public licences illustrating greater understanding than non-professional drivers who held C or A and A public licences.	1. The study was limited to the Soloraya area of Central Java Province; the outcomes' representativeness to other areas or territories in Indonesia may be limited. 2. The sample size of 202 survey participants was small, and a larger sample size would yield more reliable and valid results. 3. The study did not consider other potential factors that could influence traffic sign comprehension, such as education level, driving experience, or familiarity with the local road network, which could have influenced the results.
Ben-Bassat & Shinar, (2015)	100 drivers	28 context-free and context-	Gender, driving experience & age.	Comprehensibility	Computer-based questionnaire	1. The research showed that the roadway environment did not	The study did not explicitly examine the correlation between road sign design and crash rates in

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Table 1 (*continued*)

Author(s) (Year)	Respondents	Road signs	Demographic features	Area	Methods	Findings	Gap/ Limitations
		filled Israeli road signs				significantly impact sign comprehension. 2. Older drivers demonstrated relatively poor comprehension of traffic signs compared to younger drivers. 3. Older drivers had the longer capability to understand periods, denoting the need to examine whether short training and re-familiarisation with signs can reduce these times.	a reflective way. More research is necessary to support the results more thoroughly.
Brucal et al., (2015)	96 licensed drivers from Metro Manila, Philippines	20 regulatory road signs	Not described	Comprehensibility and redesign	First is a four-category comprehension test; Next, suggest three substitute signs and evaluate them using three ergonomic design concepts. Third: Use Kepner-Tregoe Decision Analysis to choose three different indicators.	1. Years of engaged driving and licence category were considered negligible considerations, noting that understanding capacity does not vary substantially depending on these variables. 2. Ergonomic design guidelines such as spatial compatibility, conceptual compatibility, physical representation, familiarity, and standardisation were important in assessing road users' comprehension abilities.	1. The research was based on regulatory road signs in the Philippines that might constrain the outcomes' applicability to other nations or types of traffic signs. 2. Comprehension evaluation used participants' reviews, which may have introduced prejudices or inconsistency. 3. The research did not explicitly measure the effect of the newly designed signs on behaviour or road safety.
Shinar & Vogelzang (2013)	48 undergraduates from Israel's Ben-Gurion University	30 unfamiliar symbolic traffic signs	Gender, driving license ownership, driving experience & age.	Comprehension of text and symbol displays	Electronic questionnaire	1. The study discovered that sign type had a robust influence on sign cognition and reflexes. 2. Text signs were more properly understood than symbolic signs, and the response time for text signs was lesser.	1. The experiment was a shorter representation of real-world driving circumstances. The findings may not be generally relevant to all driving circumstances. 2. The respondents were university students who were educated, which may not be representative of all drivers' educational standards.
Ou & Liu (2012)	30 Vietnamese and 30 Taiwanese students reside in Taiwan.	66 chosen Taiwanese road signage	Gender & age	Comprehensibility	Cardboard-based open-ended questionnaire	The comprehension of various kinds of Taiwanese road signs differed widely, and users from various ethnic and cultural backgrounds proved completely distinct levels of understanding. Before instruction, neither of the four types of road signs met the ISO 3864 understanding requirement of 67 per cent.	1. The research did not track recognition or response time. 2. The research focused on Taiwanese and Vietnamese participants, restricting the study results' applicability to other backgrounds and cultures. 3. The study did not consider demographics' effect on

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Table 1 (*continued*)

Author(s) (Year)	Respondents	Road signs	Demographic features	Area	Methods	Findings	Gap/ Limitations
						The results provide useful solutions to enhance road sign designs. They can help interface designers evaluate visual signs for various products.	understanding road signs, such as age or driving experience. 4. The yardstick used for cognition (67 per cent from ISO 3864) may still not represent the entire diversity and variance of real-world traffic sign understanding.
Kirmizioglu & Tuydes-Yaman, (2012)	1478 Turkish drivers	39 selected traffic signs	Educational background, years of driving, occupational driving requirement, average inner-city and outer-city kilometres per year, occupation, gender, number of traffic fines in the last five years, driving license class & age	Familiarity, comprehensibility, responsiveness	Open-ended questionnaire	1. Most drivers were strange with the greater percentage of the road signs. Only 12 of the 39 signs were defined by 70 % or more of the respondents. 2. More than 10 % of drivers understood five signs in the opposite direction, which is even highly risky than not recognising the sign. This includes new "No Trucks" and "No Overtaking" signs without red oblique bars. 3. Even during the transition, using both the old and new forms of these signs may lead to driver ambiguity and misapplication. 4. Transferring to past versions of these signs is impossible due to global liabilities.	2. The research was based on Ankara, Turkey, urban drivers. This might not reflect the comprehension of drivers in other countries. 3. The research did not investigate why drivers are unfamiliar with or understand road signs. 4. The investigation did not assess or correlate the efficacy of various instructional methods. 5. The researchers did not consider the effect of demographic factors like age or driving experience on drivers' sign cognition
Sheykhfard et al., (2022)	Drivers around elementary schools	Studied the effectiveness of four distinct signs	Not described	Road safety awareness, comprehensibility	Used IoT technology to assess the influence of signs on vehicle speed-Experimental	Two signs were particularly effective in slowing down traffic, with sign #4 consistently increasing safety over six months	The study may not have considered the influence of external factors on the effectiveness of signs.
Kavianpour et al., (2023)	Drivers of light and heavy vehicles	Investigated the impact of road signs and other traffic-calming measures.	Not described	Familiarity, road safety awareness	Investigated the influence of traffic calming measures on speeding habits using various signs-Experimental	Traffic slowing induced cautious behaviour up to a certain point, beyond which there was a gradual increase in speed	The study may not have considered the long-term effects of traffic calming measures.
Sheykhfard et al., (2023)	Drivers near uncontrolled median openings in Mahmoud Abad, Iran	Explored the efficacy of regulatory signs, with a focus on multi-message signs	Not described	Road safety awareness, familiarity	Used an IoT test system to assess the impact of signs on speeding behaviour-Experimental	Installing signs immediately reduced speeding behaviour, with multi-message signs twice as effective as single-message signs. Only multi-message signs successfully minimized speed limit infractions	The study may not have considered the influence of driver familiarity with different sign types.

The knowledge of traffic safety and comprehension of 25 regional traffic signs among foreign visitors to Thailand was examined by Choocharukul & Sriroongvikrai (2017). Personal variables like gender, age, nationality, possession of a driver's licence, and overseas driving experience were considered in this poll. In addition, factors such as trip length, destination, form of transport, and the number of trips were considered. In their own words, the responders describe the connotation of the signs. The results showed that the place of residence of the visitor plays a significant role; Asian respondents placed highest among those who misread the local road signs, as contrasted to those from North America, Australia, Africa, and Europe. Adding text to home-grown signage reduces their comprehension because it exclusively uses the local tongue, making it harder for foreign visitors to understand. In contrast, Shinar & Vogelzang (2013) affirmed that adding text to signs increases drivers' comprehension and language corresponding to the driver's profile could help alleviate this issue.

As part of the familiarity test, Taamneh & Alkheder (2018) asked respondents if they were familiar with the assessed traffic signs while driving. In contrast, the comprehensibility test was conducted as Kirmizioglu & Tuydes-Yaman, (2012) by asking about the meaning of the tested signals. The findings indicated that the evaluated traffic signs' familiarity level is more significant than their comprehension level. The decision tree algorithm was then used to identify the relevant elements influencing the driver's comprehension, including educational background, driving experience, age, and marital status.

Ghadban et al. (2018) examined how human traits quickly affect people understanding of road signals. They discovered that men drivers consistently score better than female drivers. Additionally, drivers between the ages of 31 and 45 may be better able to comprehend traffic signs than those between 18 and 22 and 23 to 30 and 46 and older. Only particular variant message signals significantly impacted nationality and linguistic traits. The data were collected inside the university, so educational level did not substantially impact it.

Bañares et al. (2018) conducted a more detailed study using a three-stage process without considering the respondents' characteristics. In the Philippines, forty road warning signs were tested for preliminary comprehension by 90 licenced drivers to obtain the average precision for each sign in four areas (correct, partial, incorrect, opposite meaning) (Kirmizioglu & Tuydes-Yaman, 2012; Ben-Bassat & Shinar, 2018). Twenty-one traffic warning signs received scores below 85 %. They did not fulfil the comprehensibility level requirements set by ANSI. 21 Warning signs with low understandability scores are examined again by the same participants considering ergonomics in signage design. Three designs for the signs were created using three sets of results as a basic template. Ninety respondents tested the twenty-one selected alternative designs for the signs to determine their level of comprehensibility at the initial stage. The final stage involved asking five specialists to help evaluate the three potential designs using the above five ergonomic criteria. Three designs were compared using the analytical hierarchy process to decide the best. The results were compared to assess how effective the substitute designs were.

Ben-Bassat & Shinar (2018) examined the impact of traffic sign differences on drivers' cognition. Israel's Ben-Gurion University participants performed a computerised comprehension test alongside 140 licenced engineering students in this study. Participants were required to write the meaning of each of the twelve Israeli and international traffic warning signs displayed one at a time. Each sign includes three options: changing the colour, somewhat altering the icon symbol, and significantly altering the icon symbol. The test took the participants' response times to each sign into an account. Setaidji and Sodikin (2016) completed similar work with different symbols. The focus of the investigation output, however, was unlike. Other countries' participants did not significantly affect the understandability ability and reaction rate to apprehend sign variants. As a result, it is not regarded as impaired driving. Furthermore, it was asserted that the significance of ergonomic principles (familiarity, standardisation, and compatibility) as criteria for comprehending traffic signs was refuted by this research.

Kaplan et al. (2018) suggest examining the relationships between apparent and hidden features of road signs, changes in perceived safety, road signs and the volume of information supplied. Evidence on socioeconomic traits, driving frequency, habits, and style, as well as the demand for closure among road users, which was assessed using two established psychometric scales, were collected by web-based survey. To obtain a credible estimate, 753 Hungarians with knowledge of travel and traffic took part in the study. Using a structural equation modelling method, the following relationships could be estimated: (i) The driver's information processing and driving style are associated with the sense of safety enhancement in addition to understanding traffic signs (ii) Since road signs promote safety changes with gender, driving frequency and behaviours and age to minimise conflict is made to be a more complex work due to the influence road users characteristics (iii) In establishing self-explanatory roadways, the road design should abide by three sustainable safety principles (iv) In order to fulfil the various needs that drivers have for feeling safe, solutions should consider individualised driving support.

Bañares et al. (2018) assessed the efficiency of the Philippines' warning signs regarding comprehension. They modified these signs according to ergonomic principles. The modified alternatives are chosen using the Analytic Hierarchy Process (AHP) to reach an objectively grounded decision. 21 of the 40 Philippine traffic warning signs that were evaluated failed to meet the ANSI criteria for comprehension of 85.00 per cent. This suggests that using ergonomic principles considerably raises the degree of driver comprehension.

Ben-Bassat, (2019) examined how quickly people could pick up new road signs and how much it affected how well those signals adhered to ergonomic principles for symbol design in Israel. The compatibility of the 30 signage not used in Israel was examined in the initial phase. The signs were separated into "ergonomic" and "non-ergonomic". The final phase involved administering and comparing comprehensibility tests on 33 teenage drivers-in-training. Results revealed a strong design main impact, with ergonomic signs related to a greater comprehension level than non-ergonomic signs.

Ben-Bassat et al. (2019) conducted a study on Traffic sign evaluation by experts: traditional versus alternative designs. The study develops theoretical and methodological foundations for assessing traditional and non-traditional sign designs. Thirty-one signs and 1 to 3 alternatives for each sign were used to test the compliance of 3 ergonomics principles. The signs were assessed based on how well

they followed the guidelines by 27 human factors and ergonomics specialists from 10 nations. When variance across alternatives was analysed, it was found that 61.29 % of the signs had alternate designs that were acknowledged higher grades for their ergonomics design. In addition, earlier research observed a strong association between the experts' judgments and comprehension. In conclusion, many nations still utilise signs despite better alternatives.

In order to determine the best training for improving motorcycle riders' knowledge of traffic signs, Dewi et al. (2019) looked at the relationship between training and sign type. The study examined how training and sign type impacted motorcycle riders' comprehension of signs. Pre- and post-tests were used in a 3x2 (Training: training vs control) study with three distinct sign types (command, regulatory, and warning signs). A mixed-design study was conducted on 79 motorbike riders in the greater Jakarta area aged 18 to 27. The experimentation was carried out using a computer. To the training and control groups, participants were apportioned at random. The amount of sign understanding was then assessed. The lowest levels of comprehension for group warning indicators were seen in the pre-and post-test analysis results. A mixed factorial Analysis of Variance (ANOVA) revealed a significant interaction effect between training and sign type on sign comprehension before and after training. The training group showed the most significant improvement in understanding warning signs.

Hou & Yang (2021) measure and evaluate the probable effects of events on traffic sign comprehension. Typically, tests of behaviour and questionnaires are used to gauge sign comprehension. To gauge sign comprehension, however, biometric indicators have also been established. By assessing event-related potentials, this study examined the brain indications underpinning the interpretation of traffic signs. The paradigms of Stimulus 1 and Stimulus 2 were adopted. A separate experiment on recognising signs was conducted in a laboratory setting with 60 participants divided into two groups. Greater N300 and N400 amplitudes were linked to the misunderstanding. According to the study, the duo amplitudes have effective cognitive indicators for road sign comprehension, evaluation, and predicting drivers' behaviour.

Robielos & Lin (2022) investigated Filipino motorists' and nondrivers' comprehension of traffic signs in Metro Manila. The study assessed seventy-three road signs for corresponding precision, cognitive design components and speed. 60 Filipinos (30 drivers and 30 nondrivers) participated voluntarily in the study for a comprehension test. A matching-based comprehension exam identifies correct and incorrect responses by matching the traffic sign with the most appropriate reference name. For a sign to be considered acceptable in a matching test, it must score at least 67 per cent accurately on a comprehension test. 27 of 73 traffic signs failed to meet the ISO 3864–1 criteria for 67 per cent comprehension for matching accuracy. Drivers than nondrivers could more accurately match both regulation and warning indications. The matching speed and accuracy were the worst for symbols representing traffic signs. Matching precision and timing were significantly improved when traffic signs previously provided as symbols were combined with text. However, the best matching accuracy and turnaround time were only found in signs displayed as text. The cognitive design elements' complexity, familiarity, concreteness, and semantic distance that measure a sign's design were also evaluated. Cognitive design elements had a positive link with matching accuracy for both regulatory and warning sign indications but a negative correlation with warning sign matching time. Correlations were also found between cognitive design elements and sign-matching speed and accuracy. Concreteness, semantic distance, and familiarity are the crucial cognitive design elements that traffic sign designers must consider increasing comprehension and traffic safety.

A thorough review of the literature on comprehending signage intended for any road user was conducted by Berrio et al. (2022). The study discovered that drivers often need help understanding the meaning of traffic signs. Several vital traffic signs have demonstrated excellent levels of comprehension across several nations. Others, though, can only be fully understood in specific settings. Traffic sign comprehension levels can be raised by using ergonomic design concepts. A proper understanding test must be conducted on various road users, and efforts must be made to guarantee that ergonomic concepts are included in the design of traffic signs.

Kavianpour et al., (2023) conducted a study on the "Effectiveness of Traffic Calming Zone in Crash-Prone Areas: A Case Study in Iran." The study investigated the impact of road signs and other traffic-calming measures on the speeding habits of both light and large vehicles. The study revealed that traffic slowing induces cautious behaviour in vehicles up to a certain point, beyond which there is a gradual increase in speed. These findings underscore the crucial importance of implementing traffic calming measures in crash-prone locations, advocating for intermittent interventions in successive crash-prone zones. Connecting this research to "Ergonomic Principles of Road Signs Comprehension: A Literature Review" facilitates a better understanding of how road signs, as a traffic-calming measure, influence drivers' behaviours, enabling the development and application of effective traffic-calming tactics that save lives on the road.

In 2022, Sheykhfard et al. conducted a study on "Improving Traffic Safety near Schools in Outskirts Areas through Internet of Things (IoT): a Case Study in Iran" highlighting the effectiveness of four distinct signs. The researchers used Internet of Things technology to assess the influence of these signs on vehicle speed around elementary schools in Babol County, Iran. The initial 30-day trial demonstrated the efficacy of the signs in slowing down traffic, with two signs proving to be particularly effective. Sign #4 consistently increased safety throughout the subsequent six-month period with a 95 % confidence level, whereas the influence of sign #2 gradually decreased. This study emphasizes the need for strategically placing specific signs to achieve optimal outcomes and provides significant insights into the dynamics of traffic safety interventions in outskirt neighbourhoods, especially those around schools. This research aligns with the broader investigation of how road signs affect drivers, as related to "Ergonomic Principles of Road Signs Comprehension: A Literature Review.".

Sheykhfard et al., (2023) conducted a study titled "Evaluating Driver Response to an Advanced Speed Display near Uncontrolled Median Openings" evaluating the efficacy of various signage in Mahmoud Abad, Iran, next to uncontrolled median openings. The study found that installing signs immediately reduced speeding behaviour using an IoT test system, with multi-message signs proving twice as effective as single-message signs. These results, which highlight the influence of various sign types on driver behaviour, are consistent with the literature study on ergonomic principles of road sign comprehension. The finding that only multi-message signs can

successfully minimize speed limit infractions introduces a level of specificity. By incorporating these crucial elements into the literature review, the study's findings, where they connect with prior knowledge on road sign comprehension, can be fully understood in terms of how road signs affect drivers' behaviour.

2.1. Comprehension-based ergonomics for traffic signs

2.1.1. Human traits

Users' attributes are taken into consideration when researching traffic sign comprehension. This could be crucial for deciphering the indicators' successful and potent communication messages (Diop et al., 2019). The communication HIP model also prioritises personal traits (Mayhorn & Wogalter, 2010). Researchers must consider several personal elements to identify a connection between respondents' human traits and their interpretation of traffic signs. Educational background, gender, driving experience, and age are the most common personal factors when analysing traffic signs. Different correlations exist between age and traffic sign comprehension. A study shows no appreciable variations between older and younger drivers' signage comprehension (Bham & Leu, 2018). Darko-Babi et al. (2020) suggested that younger drivers have an added significant edge over older drivers when comprehending traffic signs.

Additionally, gender traits might produce different analytical outcomes. Some researchers contend that male drivers interpret traffic signs more thoroughly than female drivers. Other studies may have produced different findings about male and female drivers. How long a person has had a driving licence, which serves as a licence to drive legally, is typically related to how much driving experience they have. the amount of driving experience they have. More experienced drivers comprehend traffic signs better than less experienced drivers (Bansal & Kockelman, 2018). At the same time, some contend that this is not always the case. This may be due to experienced drivers' greater familiarity with the road than inexperienced drivers. The degree of understanding of traffic signs is often strongly correlated with educational background (Bansal & Kockelman, 2018). This finding may indicate that drivers with undergraduate degrees learn the material more quickly and can remember and process it more effectively (McDermott & Zerr, 2019). The situation might alter if respondents in the sample came from a different university. Therefore, the findings of numerous past studies on understanding traffic signs and their relevance to human characteristics must be more consistent.

2.1.2. Ergonomic principles in the design of road signs

Road sign comprehension and design are interrelated, and improving the signs' level of understandability requires the application of ergonomic design concepts (Ben-Bassat et al., 2021; Li & Wan, 2022). Most studies on the comprehension of signs between 2012 and 2018 refer to earlier studies; hence, additional study is required. Shape, colour, and symbol are the three most crucial ergonomic design elements for traffic signs (Ben-Bassat et al., 2019). Wang et al. (2019) defined some standards for designing and assessing traffic sign indicators: learnability, comprehension, readability, distance, conspicuity, and reaction time. Quite a lot of research that considers ergonomic principles in design cites Ben Bassat and Shinar and Shinar et al. as well as Shinar et al. Sanders and McCormick presented the initial five ergonomic guidelines for sign design which are as follows: compatibility, conceptual, familiarity, physical representation, spatial compatibility based on driving experience, and standardisation (Brucal et al., 2015; Bañares et al., 2018). Space, information orientation, and directional consistency are all aspects of spatial compatibility. Adapting symbols and codes to people's interpretations is known as conceptual compatibility. The physical representation is the degree to which the content of signs corresponds to reality (reliable codes are used to determine each sign's size, colour, and shape).

Optimizing the complexity, familiarity, concreteness and semantic distance in road sign design guarantee that signs are legible, easy to interpret, and swiftly interpreted by drivers, leading to better and effective traffic flow. The complexity of a road sign's design or text indicates to how sophisticated or difficult it is. This typically contain several parts, colours, or signs, making it difficult to interpret rapidly. Signs that are simple and plain are more efficient since they lessen cognitive strain and provide for quicker understanding (Ben-Bassat, 2019). Familiarity is the degree to which a driver comprehends a traffic sign is determined on prior knowledge and experience. Drivers tend to recognise signs that adhere to known rules and global standards. Familiarity improves comprehension and allows drivers to react positively to the content on the sign (Akple et al., 2020). The degree to which a road sign's message is explicit, precise, and consistent is referred to as concreteness. Signs with a simple mandate offer little space for interpretation. Signs that are vague or conceptual might cause misunderstanding and misinterpretation, raising the likelihood of an accident (Ng & Chan, 2008). The semantic distance of a traffic sign relates to how well its meaning corresponds with the driver's known cognitive representation or understanding. Road signs with relatively short semantic distance are easier to comprehend because they accurately reflect the driver's anticipations. Longer semantic distance signs necessitate higher mental effort to understand because they deviate from what the driver expects (Khalilikhah & Heaslip, 2016).

2.1.3. Features of cognitive design for traffic signs

Traffic sign knowledge may also consider cognitive design elements, including semantic distance, familiarity, complexity, concreteness, and meaningfulness (Liu et al., 2019). The rate of a user's contact with the influences of the signs of their familiarity. How symbols depict actual people, things, or materials is referred to as their concreteness. Complexity has to do with the specifics and components of symbols. Meaningfulness refers to the ability of the signs to communicate specific symbolic meanings. Semantic distance quantifies how closely a sign relates to what it is meant to represent. Typically, studies on the features of the cognitive design for traffic signs involved asking participants to rate each sign using a scale of 0 and 100 for each design element (Ang et al., 2019). In order to solve the issue and make the supplied alternative designs more user-friendly for drivers, with the help of studies on cognitive components of traffic sign design, signage designers can modify the signs with low comprehensibility ratings (Bañares et al., 2018).

2.1.4. Understanding traffic Signs: Cultural issues

The relationship between comprehensibility level and the regional socio-cultural background is a more contemporary research area in sign comprehension. Examples of this are studies by Choocharukul & Sriroongvikrai (2017) that examined how international visitors to Thailand perceived traffic signs. Ou & Liu (2012) assessed how well two groups of drivers in Taiwan and Vietnam understood traffic signs. Furthermore, earlier investigations by Ben-Bassat & Shinar (2006); Ng & Chan (2016) examined cultural influences on sign comprehension and supported similar findings. Road users from various cultural and linguistic backgrounds had varying levels of understanding of traffic signs (Ou & Liu, 2012; Ghadban et al., 2018). The level of comprehension was not considerably impacted by sign variations from other countries that drivers might need help recognising. Understanding unfamiliar signs was more accurate when a text accompanied a symbol (Wali et al., 2019). However, the level of the assignments' comprehension could be reduced if the extra text utilised a language that non-local road users needed to comprehend (Choocharukul & Sriroongvikrai, 2017). A possible substitute is to employ language appropriate to the road users' profiles in the content of road signs.

3. Methods

The procedures involved in analysing and evaluating the literature included establishing the keywords, and the study's scope, doing a literature search, evaluating the studies, and interpreting and synthesising the results, as shown in Fig. 3. From 2012 to 2023, searches were conducted on articles in the electronic databases of Web of Science, Scopus, Google Scholar, Semantic Scholar, Science Direct, Cambridge Core, and JSTOR. The following search string was used to find publications in various databases based on their title, abstract, or keywords: (Comprehension AND ergonomic principles of design AND road signs AND safety). Manuscripts were found by searching subjective databases and the references of papers deemed pertinent to the evaluation.

Two trained independent researchers assessed all articles on Rayyan. Rayyan is a forum for intellectual collaborative research for systematic and literature reviews (Ouzzani et al., 2016). When there were disagreements, a third researcher reached an agreement on the importance of each article to the literature analysis. In the stages of data retrieval for quality analysis and record keeping of study characteristics, the same process with two researchers was used. Studies excluded were: 1) not carried out within the context of road safety; 2) evaluate road signs for industrial safety; 3) focused on algorithm design; 4) were presumed to be of poor quality based on the current review's performance metrics. The chosen papers were evaluated and analysed to explain the results based on the search terms utilised as shown in Table 2.

Mendeley (version 1.19.8) was used to deduplicate all identified citations. A data gathering form was created in a Microsoft Excel (MS) spreadsheet before the data exploration process began. Author, year, respondents, road signs, demographic features, area, methods, and findings and limitations were among the information extracted from eligible articles, as shown in Table 3. Author(s) (Year), quality qualification, defined objectives/ hypothesis, defined road users, justified sample, study design, study population, defined road signs, defined variable associated with ergonomic principles, define comprehension metric and comprehension level are information covered in Table 3. For each road sign, the comprehension level of a cohort is determined by dividing the distribution of all respondents who have accurate response by the highest number of points acquired if all respondents' answers were correct. A Preferred Reporting Item for Systematic and Meta-Analysis (PRISMA) flow diagram summarises the study's selection process, as shown in Fig. 4.

4. Results and discussions

4.1. Search results

This study's search strategy yielded a total of 11,565 articles. After removing duplicates, there were 11,500 unique articles left. These articles were screened for eligibility, yielding 953 full-text articles for consideration. 933 articles were excluded. Finally, following the screening process, 20 eligible articles were included in this study.

4.2. Study characteristics

20 studies conducted in 11 countries were included: Israel- 4, Philippine-3, and the remaining 8 studies were conducted in Iran, Qatar, Jordan, Thailand, Hong Kong, Indonesia, Vietnam, Taiwan and Turkey. Among the eligible studies, 3 used computer-based questionnaires; 5 used experimental; paper-based questionnaires, open-ended questionnaires and scale numerical responses (Kepner Tregoe Decision Analysis and Analytical Hierarchy Process) have 2 papers each; matching based comprehension exam, an experiment in the form of pen and paper questionnaire, experiment in laboratory settings, online multiple choice questions, multiple choice survey on paper and cardboard based open-ended questionnaire have 1 paper each. Additionally, 10 articles did not have demographic information, and 10 had demographic information. Furthermore, 17 articles deal with the comprehensibility of road signs, 2 articles deal with familiarity, and 1 article deals with re-useability of road signs. Based on the category of respondents, 14 studies used drivers as respondents, 3 studies used university students, and the remaining studies used 1 ergonomic expert, motorcycle rider and foreign tourist, respectively.

4.3. Classification of road signs

Idris & Mustapha, (2019) classified signs into three categories: guiding, prohibition and warning signs.

4.3.1. Warning signs

These signs often warn vehicles of impending risks or changes in the road. The driver's comprehension may differ depending on his or her acquaintance with these hazards and the clarity of the sign design. Sign visibility, road conditions, and driver experience are all factors that influence comprehension. Examples are "Dead end", "Roundabout" and "Slippery road".

4.3.2. Prohibition signs

These signs state that certain acts or vehicles are not permitted in a given region or under certain conditions. Knowledge of these signs is required to guarantee that traffic rules are followed. The sign's clarity and knowledge of local regulations are critical. Examples are "Stop," "Yield," and "No entry".

4.3.3. Guide signs

These signs tell drivers about the route structure, directions, and available services. The driver's driving skills and the requirement for the information presented may influence comprehension. This signage must be both visible and legible. For example, "One way" and "No parking".

Driver understanding of road signs depends on the type of sign, its design, and the driver's awareness and experience. For instance, due to the complexity of the danger they imply, warning signs are more difficult to understand. Guide signs are often widely comprehended when visible and clear. For effective comprehension, prohibition signs must be designed clearly and meet the local statutory driving provisions on the road. Enhancing signage visibility and design can benefit all road users.

4.4. Comprehension level of road signs

Seventeen research reported the comprehension levels of 268 various road signs. Most road signs understood by a large percentage of participants in one country (>67 %) were also understood by a substantial percentage of participants in other countries where the sign is installed. On the contrary, several road signs were regularly understood by less than 67 per cent of study participants. Other signs, on the other hand, had acceptable comprehension levels in at least one country (>67 per cent of participants comprehended the sign) despite demonstrating poorer comprehension levels in at least another. Consequently, the stated understanding values varied from negative numbers (showing poor comprehension) to positive percentages (indicating good comprehension). This range shows the differences in how effectively different individuals and groups understand road signs. The comprehension levels vary across different research for the same road sign. This could be due to a variety of reasons such as participant demographics, study methodology, and local contextual factors. Table 4 shows the comprehension level of the road signs most evaluated in the review.

Based on International Standard Organization (ISO, 3846 and 39001), 268 road signs were reviewed out of which, 112 (41.79 %) road signs are associated with lower comprehension scores and may pose a higher risk to road users who many not fully understand their meaning. 156 (58.21 %) road signs associated with higher comprehension scores and likely understood by road users. Fig. 5 shows a pie chart with lower and higher comprehension scores.

4.5. Categorizing the road signs based on the International Organization for Standardization (ISO 3864-3)

A suitable way is to categorise traffic signs based on the International Organization for 0p;'/Standardization (ISO 3864-3) requirements (threshold of 67 per cent). This standard establishes the guidelines for pictorial symbols used on road signs to improve comprehension and efficiently transmit information. Furthermore, ISO 3864-3 highlights rules for the design of graphical symbols and safety colours to guarantee that signs are understandable by a wide range of people. Analysing the results of road signs using these principles can provide useful insights into the effectiveness of road sign designs and contribute to ergonomic principles of road sign interpretation. The ISO 3864-3 categorization of road signs is outlined below:

1. **Consistently High Comprehension Signs:** These signs exhibit high design principles and have relatively high comprehension levels throughout studies, typically nearing or exceeding 90 %. They effectively communicate their true intent and are

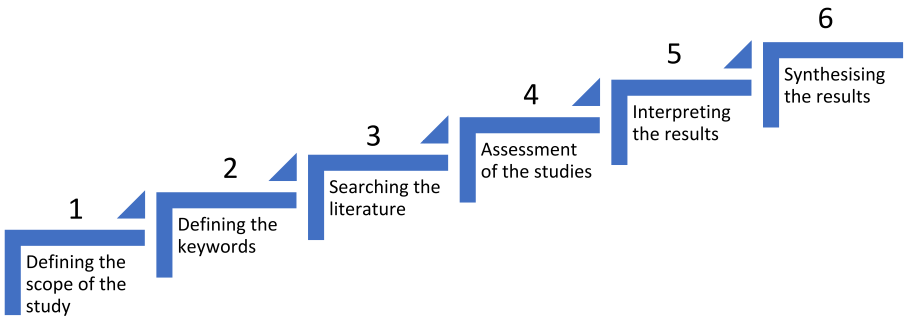

Fig. 3. Methodology.

Table 2
List of search terms used for the literature review.

Terms related to Road	Terms related to Motorists	Terms related to Road signs	Terms related to Comprehension
Bridge OR Crosswalk OR Intersection OR Path OR Road OR Sidewalk OR Traffic OR	Bicycle OR Biker OR Cyclist OR Driver OR Motorcyclist OR Pedestrian	Colour OR Design OR Icon OR Shape OR Sign OR Symbol OR Traffic light	Comprehension OR Ergonomic OR Human factor OR Recognition OR Safety OR Understand

comprehended by drivers easily. Road signs such as Dead end 

(Hou & Yang, 2021), end of speed limit 
(Ben-Bassat et al., 2019), Stop 

(Setiadji & Sodikin, 2016), No parking 

(Shinar & Vogelzang, 2013), and no entry 

(Ben-Bassat & Shinar, 2015) appear to have sufficiently good comprehension levels in the studies. These signs could serve as examples of effective design ideas that aid in comprehension. Other signs with high comprehension scores throughout studies include "Yield 

", "No U-turn 
", "Bike lane 

", "Zebra crossing 
" "No overtaking," and "Min. (30) speed limit 

" These signs appear to have designs that blend effortlessly with ergonomic principles, as observed by authors such as (Dewi et al., 2019; Ben-Bassat et al., 2021; Robielos & Lin, 2022). This synchronisation promotes easy detection and comprehension, highlighting their usefulness in communicating critical information to road users.

2. **Signs with Consistently Poor Comprehension Signs:** These signs appear to have consistently low comprehension levels, suggesting that their design may be less effective in transmitting their underlying message, despite initially attaining negative values. This could imply design, visibility, or familiarity concerns that need to be rectified. Bus lane 

(Robielos & Lin, 2022), Right line must turn right 

(Ben-Bassat, 2019), T-junction 
(Dewi et al., 2019), Slippery road 
(Brucal et al., 2015), and Construction zone 
(Bañares et al., 2018). Some road signs, such as "Speed limit 

", "Motorway 
", "End of overtaking 
", "One way 

" "Diverging road 
" and "T and Y intersection 
" consistently have low comprehension scores. According to scholars such as Hou & Yang, (2021), these signals may include design features that are less simple or difficult to successfully express their interpretations. These findings highlight potential flaws in its ergonomic features, underlining the need for design revision.

3. **Signs with Mixed Results (Design Variability or Contextual Factors):** These signs have varying levels of comprehension across studies, implying that their usefulness may be modified by influencing variables such as demographics or regional variances. Examples include a roundabout 
(Choocharukul & Sriroongvikrai, 2017), side road right junction 
(Taamneh & Alkheder, 2018), no passing 

and end divided road 
(Ghadban et al., 2018), no overtaking 
and level crossing with barrier 
(Ou & Liu, 2012), and slowing down (Animals) 

, accident region 

(Ben-Bassat & Shinar, 2018). Furthermore, a set of road signs, such as "Roundabout 
" "Right line must turn right 

", "Road narrow 
", "Signal ahead 
" "Cross road 
", "Winding road 
", "No trucks 
" and "Traffic control by officers on duty (Temporary) 

" depicts a wide range of comprehension ratings across studies. This gap can be attributed to reasons other than ergonomic design principles. Cultural context, user familiarity, and unique regional concerns, as discussed by authors such as Choocharukul & Sriroongvikrai (2017), may all play a role in each of these swings in understanding ratings.

4.6. Road sign comprehension across countries

The findings on road sign comprehension varies across countries, revealing both similarities and differences. The similarities

Table 3
Quality assessment of identified articles.

S/N	Author(s), (Year)	Quality factors										
		Quality Qualification	Defined objectives/ hypothesis	Defined the road users	Demographic features	Design	Presented study population	Defined road signs	Defined variables associated with ergonomic principles	Described statistical methods	Define comprehension metric	Comprehension level
1	Robielos & Lin, (2022)	H = 80 %	1	1	0	1	1	0	1	1	1	1
2	Hou & Yang (2021)	H = 70 %	1	1	0	1	1	0	0	1	1	1
3	Dewi et al. (2019)	H = 90 %	1	1	1	1	1	1	0	1	1	1
4	Ben-Bassat et al., (2019)	H = 80 %	1	1	0	1	1	0	1	1	1	1
5	Ben-Bassat, (2019)	H = 80 %	1	1	0	1	1	0	1	1	1	1
6	Ben-Bassat & Shinar, (2018)	H = 90 %	1	1	0	1	1	1	1	1	1	1
7	Bañares et al., (2018)	H = 70 %	1	1	0	0	1	0	1	1	1	1
8	Ghadban et al., (2018)	H = 90 %	1	1	1	1	1	1	0	1	1	1
9	Taamneh & Alkheder, (2018)	H = 90 %	1	1	1	1	1	1	1	1	0	1
10	Choocharukul & Sriroongvikrai (2017)	H = 80 %	1	1	1	1	1	1	0	1	0	1
11	Ng & Chan (2016)	H = 80 %	1	1	1	1	1	0	0	1	1	1
12	Setiadji & Sodikin (2016)	H = 90 %	1	1	1	1	1	1	0	1	1	1
13	Ben-Bassat & Shinar, (2015)	H = 90 %	1	0	1	1	1	1	1	1	1	1
14	Brucal et al., (2015)	H = 70 %	1	1	0	1	1	0	0	1	1	1
15	Shinar & Vogelzang (2013)	H = 80 %	1	1	1	1	1	0	0	1	1	1
16	Ou & Liu (2012)	H = 80 %	1	1	1	1	1	0	1	1	0	1
17	Kirmizioglu & Tuydes-Yaman, (2012)	H = 90 %	1	1	1	1	1	0	1	1	1	1
18	Sheykhfard et al., (2022)	H = 90 %	1	1	0	1	1	1	1	1	1	1
19	Sheykhfard et al., (2023)	H = 80 %	1	1	0	1	1	1	1	1	0	1
20	Kavianpour et al. (2023)	H = 90 %	1	1	0	1	1	1	1	1	1	1

Keys: Present (1); Absence (0); H = High quality; M = Medium quality; L = Low quality.

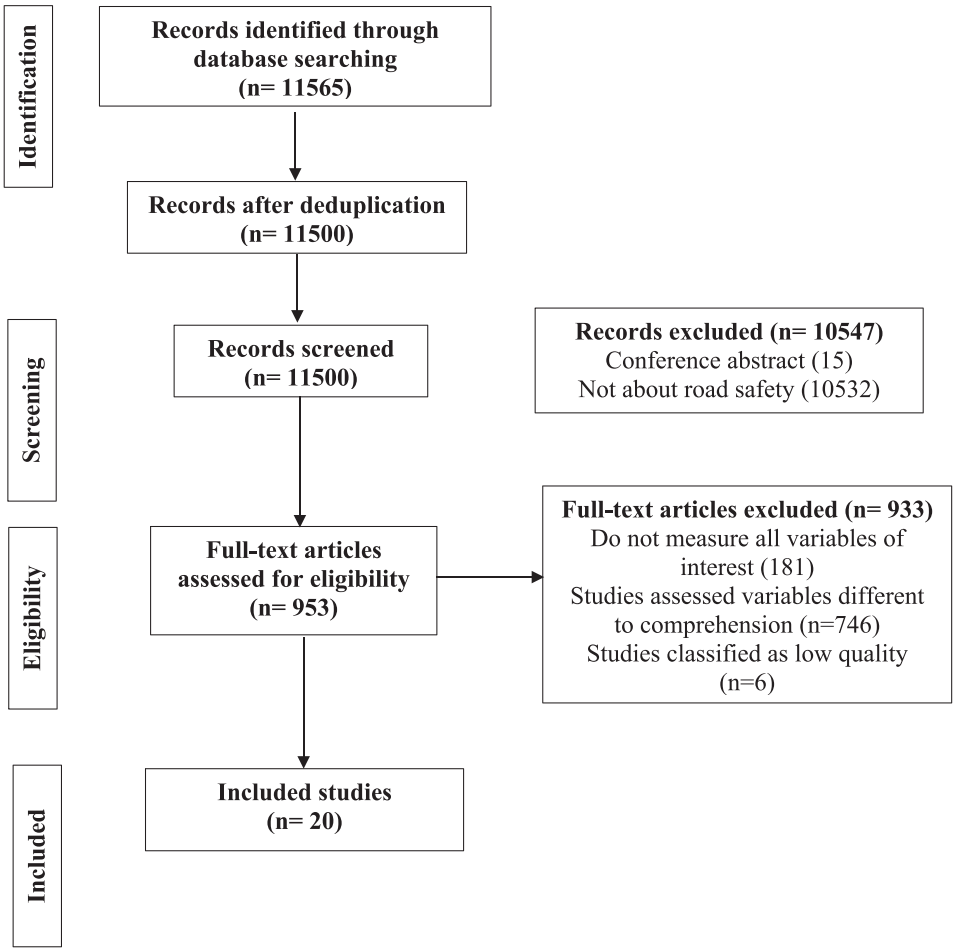

Fig. 4. PRISMA flow diagram.

Table 4
Comprehension level of the road signs most evaluated in the review.

Road sign	Authors																
	Robeilos & Lin (2022)	Hou & Yang (2021)	Dewi et al (2019)	Ben-Bassat et al (2019)	Ben-Bassat (2019)	Ben-Bassat & Shinar (2018)	Banares et al (2018)	Ghadban et al (2018)	Taamneh & Alkheder (2018)	Choucharukul & Sriroongvikrai (2017)	Ng & Chan (2016)	Setiadji & Sodikin (2016)	Ben-Bassat & Shinar (2015)	Brucal et al (2015)	Shinar & Vogelzang (2013)	Ou & Liu (2012)	Kirmizioglu & Tuydes-Yaman (2012)
Bus lane (PS)															-26.00		
Dead end (WS)									86.90				96.00		74.50	14.33	
Motorway (GS)											87.72		92.00				
End of speed limit (GS)													91.00		-25.50		
Stop (PS)	95.00						87.78	84.70					99.00				
No parking (PS)	95.00	92.20		33.00	11.25				86.00					79.00	52.00	70.00	
Roundabout (WS)			37.80			51.00	88.98		79.00			89.00					
U-turn (WS)			39.5														
Left turn (WS)	100.00		46									69.00					
Giveway (WS)	97.00	36.80					51.11		71.00								
Y-junction (WS)	93.00	96.70					86.67										
Road narrow (WS)	98.00	93.30					85.56		71.00				88.00		34.00		
Spillway (WS)	95.00	94.40					66.67										
Flooding area ahead (WS)	95.00						86.67										
Hump ahead (WS)	90.00	92.20					88.89		89.00				74.00		13.50		92.00
Right line must turn right (GS)	93.00																
Speed limit (60) (GS)	93.00																
Wheel chair crossing (GS)	92.00						23.33										
No entry for pusel carts (PS)	92.00																
No parking tow away zone (PS)	90.00																
No entry for motorcycles (PS)	88.00																
No entry for jeepsneys (PS)	88.00																
No jaywalking use overpass (PS)	88.00																
loading and unloading zone (PS)	87.00																
Bus-puj stop no parking (PS)	85.00																
No jaywalking (PS)	83.00																
No entry for vehicles with trailers (PS)	75.00																
Bus-stop no parking at this size (PS)	62.00																
No jaywalking use pedestrian cross (PS)	62.00																
Merging traffic (PS)	53.00																
Puj stop no parking at this side (PS)	52.00																
Keep right (PS)	38.00																
One way (GS)	25.00																
School children crossing (GS)	37.00							93.80									
Diverging road (GS)	20.00																
No entry for tricycles (PS)	12.00																

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Table 4 (*continued*)

Speed de restriction (PS)	0.00				77.50		85.56	69.60										
T-junction (GS)	87.00							83.20										
Stop at intersection ahead (PS)	87.00																	
Cross only at pedestrian crossing (PS)	85.00		39.50				90.00											
Signal ahead (GS)	80.00						88.89											
Cross road (WS)	55.00																	
Curve (WS)	55.00					85.56												
Winding road (WS)	48.00						86.67											
Sharp turn (WS)	47.00						52.22											
Divided road (GS)	40.00						38.39											
End divided road (PS)	33.00																	
Rail road crossing with light (PS)															-63.50			
left turn then right (WS)															-14.00			
Build up area (end) (GS)															-42.00			
Bicycles (GS)															16.50			
No entry for vehicle carrying explosive + water pollutant (PS)					13.75										-74.00			
Road end (PS)								83.20							-81.00			
Keep right (PS)															-79.50	95.33		
Diagonal rail road crossing ahead (PS)															-62.00			
Rail road crossing ahead (PS)		94.40													12.00			
Truck crossing (PS)								64.60							39.50			
No left turn (PS)															65.00			
Truck entrance (PS)															-55.50			
End of paved road (PS)															-66.60			
Congestion ahead (WS)															6.00			
Sharp curve right (WS)															58.00			
No trucks (WS)	93.00																	
Level crossing without barrier (WS)																		77.50
Snow chain compulsory (PS)																		87.00
Risk of ice (WS)																		79.00
End of overtaking (GS)																		74.00
No waiting time (PS)	100.00																	61.00
Do not block intersection (PS)	98.00																	
No stopping time (PS)	98.00																	
Right turner cross at broken lines (GS)	98.00																	
Fasten seat belt (GS)	98.00																	
No right turn (PS)	98.00																	
No entry for buses (PS)	97.00																	
No entry for bicycles (PS)	97.00																	
Bike lane (PS)	97.00						91.11											
No loading and unloading anytime (PS)	93.00																	
Priority for traffic in driver direction (GS)			34.50										42.00	46.50	13.50		78.00	
Priority for traffic in opposite direction (GS)			43.00															
Slippery road (WS)	93.00	97.80					88.89		82.00				86.00		36.00			
Priority crossroad (GS)	22.00	98.90					6.67											

(*continued on next page*)

Table 4 (*continued*)

No pedestrian (PS)											98.25				26.00		
2-way traffic sign (GS)	82.00										100.00		82.00				
Footway and cycles (GS)											94.74						
Level crossing with barrier (GS)											1.75	87.00					
Parking lot (GS)												98.00	99.00				
Bridge narrow (GS)		88.80			86.25		6.67					96.00					
No horn (GS)	98.00											96.00					
No overtaking (PS)	77.00											82.00					77.50
Zebra crossing (WS), (GS)			48.50				53.30					72.00			55.50		97.00
Max. (40) speed limit (WS), (GS)												56.00					96.00
Min. (30) speed limit (WS), (GS)	100.00											20.00	93.50		57.50		83.00
Caution (WS)												27.00	81.50				
End max. (40) speed limit (GS)												24.00					
Pass either side (GS)											89.47						
Pass angle lane (GS)												65.00					
Double bend (GS)													73.00				
Merge from right (GS)													92.50				
Construction zone (WS)													100.00				
Winding road (WS)													88.00				
Steep slope (WS)													80.00				
No passing (WS)													56.50				
No entry (PS)	90.00												99.00				93.00
No u-turn (PS)	93.00												99.00		71.50		
No end of passing zone (PS)													48.00				
Motocycle prohibited (PS)													82.00		-2.50		
Urban zone (PS)													90.00				
End of urban zone (PS)													27.00				
Yield (PS)		96.70			25.00								91.00				
Side road right junction (PS)	30.00																
Pedestrian ahead (PS)	27.00				31.25							36.00	93.50		57.50		93.00
Reverse curve (PS)	23.00						87.78										
Giveway at intersection (PS)	17.00																
Children ahead (PS)	15.00																
Sharp junction (PS)	13.00																
Hair pin curve (PS)	10.00						34.40										
Side road junction (PS)	7.00	97.80					64.44										
T and Y junction (PS)	2.00																
No passing (PS)		97.80															
End divided road		88.80															
Priority merging (GS)		98.90					43.33										
Priority junction (GS)		91.10					6.67										
Skewed intersection (GS)		94.40					57.78										
Hump bridge (GS)		90.00															
Uneven road (GS)		96.70					85.56										
Linking turns (GS)		94.40															
Cross wind (GS)		93.30															

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Table 4 (*continued*)

Right turner cross at broken lines (GS)		39.90															
Slow down (bus stop) (GS)		47.40															
Slow down (Animals) (WS)		37.10				63.33											
Slow down (Driving in rain) (GS)		43.00															
Slow down when approaching intersection (WS), (GS)		44.70															
Priotising vehicle coming from left (WS), (GS)		34.40															
Stop when level crossing bell ring (GS)		44.70															
Stop (fire truck) (PS)		47.40															
Stop (ambulance) (PS)		44.70															
Stop (head of state) (PS)		44.00															
Stop (funeral) (PS)		47.10															
Blind/ elderly people (PS)				95.00													
Horse-drawn carts forbidden (PS)				83.75													
Max. vehicle length (PS)				82.50													
Min. safe following distance between vehicles (PS)				81.25													
Accident area (PS)				75.00	29.00												
Hitch hiking is prohibited (PS)				72.50													
Traffic control by officers on duty (Temporary) (GS)				28.75													
No stopping (PS)				11.25													
Obstacle on road (PS)				6.25													
Reverse turn (GS)					51.11												
Staggered road junction (GS)						87.78											
Steep climb (GS)						92.22											
falling rock (WS)						88.89											
Low flying air craft (GS)						31.11											
Children crossing (WS)						63.33											
Cross outyat pedestrian crossing (GS)						50.00											

Key: Not Evaluated, Signs with <65% comprehension, , Signs with >65% comprehension, WS- Warning signs, GS- Guide signs, PS- Prohibitive sign

Key: Not Evaluated, Signs with < 65 % comprehension, Signs with > 65 % comprehension, WS- Warning signs, GS- Guide signs, PS- Prohibitive sign.

include familiar and simple signs. Cultural considerations, road design, and driver behaviour all contribute to differences. Countries with diverse driving cultures, for example, may have varied interpretations of warning signs.

4.6.1. Cultural factors

Cultural considerations influence road sign comprehension significantly. Drivers' interpretation and response to signs can be influenced by cultural norms and driving behaviours (Ben-Bassat & Shinar, 2015). A yield sign, for example, may be regarded as more of a suggestion in some nations and rigidly enforced in others (Ben-Bassat, 2019).

4.6.2. Road design

Sign location and visibility are influenced by road design. According to research, traffic signs situated in difficult settings, such as those concealed by foliage or congested environments, are less likely to be understood (Taamneh & Alkheder, 2018).

4.6.3. Driver behaviour

Local customs and attitudes influence driver behaviour. According to Chevalier et al., (2017), some drivers may speed or violate traffic signs, but others are more careful and vigilant. These variances have an impact on road sign comprehension and adherence.

4.7. Warning sign comprehension

The findings on warning sign comprehension revealed that complexity, familiarity, and concreteness are all important factors in understanding warning signs, according to research. Complex warning signs with several symbols or ambiguous wording are frequently less understandable. Better comprehension results from familiarity with a hazard and tangible, explicit warnings.

4.7.1. Complexity

Complex warning signs, such as those with multiple symbols or ambiguous meanings, are frequently less effective. van der Heiden et al., (2019) corroborated that drivers may find it difficult to understand the targeted threat, resulting in slower response time and

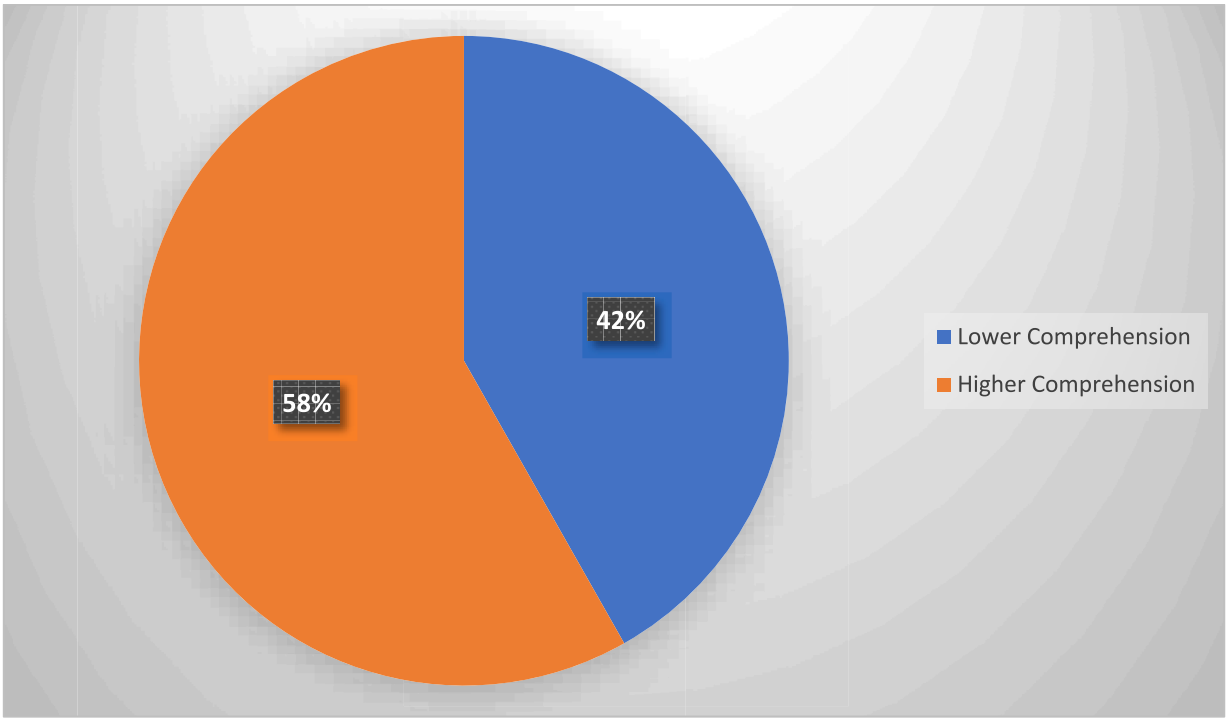

Fig. 5. Lower and higher comprehension scores.

possibly dangerous circumstances.

4.7.2. Familiarity

Familiarity with a specific risk improves comprehension greatly. Lim et al., (2013) verified that drivers who experience specific hazards on a regular basis are more likely to identify and effectively respond to warning indications.

4.7.3. Concreteness

Effective hazard communication relies on clear and realistic warning signs that convey detailed information about hazard, its location, and recommended measures (Pandit et al., 2019). Ambiguous or abstract warnings might cause confusion and poor responses.

4.8. Guide sign design

The findings on guide sign design revealed that for effective vehicle navigation, research on guide sign design highlights the need of clarity, consistency, and the reduction of cognitive burden. Clear and simple guide signs with unambiguous information about directions and destinations are more likely to be understood.

4.8.1. Clarity

Clear, readable typefaces and symbols, as well as logical arrangement and colour choices, all contribute to improved guide sign comprehension (Ben-Bassat & Shinar, 2006, 2015). Sign design ambiguities, such as ambiguous arrows or misleading phrasing, impede navigation.

4.8.2. Consistency

Sign design consistency across countries helps drivers comprehend directives. When shifting between locations, anomalies might lead to misunderstanding (Ben-Bassat & Shinar, 2006).

4.8.3. Cognitive load

Reduce cognitive strain by clarifying information on guidance signs, such as reducing the number of destinations or giving sequential information (Agrawal & Peeta, 2021). Overly elaborate signs can confuse drivers and make navigation difficult.

4.9. Prohibition sign understanding

The findings revealed that according to research on prohibition signs, clear and unambiguous signage plays an important impact in influencing drivers' adherence to traffic rules and regulations. Drivers are more likely to obey signals that offer no opportunity for interpretation.

4.9.1. Clarity and unambiguity

Prohibition signs that clearly convey the banned behaviours, such as "No parking," "No entering," or "No U-turn," are more likely to be followed. Signs that are vague or poorly designed can result in infractions (Vilchez, 2019).

4.10. Cognitive psychology theories and research methods

The findings on cognitive psychology theories and research methods revealed that road sign comprehension is supported by cognitive psychology ideas such as the Gestalt principles of perception and attention. These ideas focus on how people organise visual data.

4.10.1. Strengths and weaknesses of research methods

Various study methodologies, including as eye-tracking, surveys, and observational studies, provide useful information about comprehension patterns. Eye-tracking measures visual attention in real time, whereas surveys measure subjective perceptions (Ahlstrom et al., 2012). Observational studies provide information about real-world behaviour. However, each approach has advantages and disadvantages, and their selection is determined by the research objectives and available resources.

This analysis emphasises the critical impact that ergonomic design principles have on road sign comprehension, as shown by several researchers. Those signs with consistently high comprehension scores have designs that match these ideas. Yet, attaining the best comprehension necessitates a diverse approach. Cultural context, design clarity, and user familiarity, as discussed by authors such as Sodikin et al., (2019), must work in tandem with ergonomic principles to guarantee that road signs properly disseminate their meanings to a wide variety of people. As a result, a thorough understanding of the interplay between design, context, and user behaviour becomes critical in improving road sign effectiveness.

This extensive review aimed to assess how well road users understand different road signs and to identify the ergonomic design factors that influence understanding levels. The ability to apply ergonomic principles to road sign designs to greatly improve comprehension levels is an important conclusion of the study of Bañares et al., (2018) which shows that improved designs can significantly boost understanding, by up to 85.6 per cent. To improve comprehension, notable experts such as Ben-Bassat & Shinar, (2006) argue for adopting road signs that combine at least three ergonomic principles, as well as standardisation. The order of these concepts, though, seems opaque, highlighting the significance of a holistic design approach while designing road signs.

Familiarity emerges as a critical factor in gaining high levels of comprehension. Although familiarity helps with road sign comprehension by experience, it can be difficult for innovative or contextually unfamiliar road signs, which is especially important for travellers seeing new road signs. The complexity of a sign can affect its remembering and acquaintance, emphasising the importance of not only ergonomic design but also pilot testing spanning varied groups and public awareness initiatives. Contextually, this study emphasises that lots of studies studied subgroups of ergonomic parameters. Considering the interdependence of these issues, a comprehensive assessment including numerous components is required. Furthermore, the study's main focus on vehicle drivers (91.4 per cent of studies) raises concerns regarding other road users' comprehension of road signs meant for drivers, emphasising the importance of comprehending a broader range of road users.

Even though, there are certain limits to this review. It is applicability is limited to the research areas. Furthermore, it focuses on comprehension while ignoring factors such as sign visibility and infrastructure. Although the premise that all signs are optimally visible and intelligible is acknowledged, it may not hold in real-world settings. Finally, this review provides critical insights into traffic sign comprehension, putting light on the delicate interplay of ergonomic principles, design, familiarity, and user variety, all of which contribute to efficient road communication.

5. Conclusion

The paper examines the relationships between ergonomics and road sign comprehension, focusing on how individual differences affect road sign comprehension. It emphasises the significance of ergonomic design concepts in improving road sign comprehension for a wide range of users. Road sign design is based on shape, colour, and symbols, which influence characteristics such as readability, legibility distance, learnability, response time, and conspicuity, all of which are important for efficiently delivering information and improving road safety. The paper also emphasises the importance of ergonomic components in signage design, such as conceptual compatibility, familiarity, physical representation, spatial compatibility, and consistency, to ensure signs are aesthetically appealing, intuitive, and easy to interpret. It also goes over cognitive characteristics like complexity, concreteness, familiarity, meaningfulness, and semantic distance, which influence how people perceive and interpret road signs. These elements all have an impact on road sign comprehension. Finally, this paper has investigated the critical relationship between ergonomics and road sign comprehension. It stressed the importance of individual traits in how individuals perceive road signs, as well as the importance of adopting ergonomic design concepts to improve comprehension, particularly among varied road users. Integrating ergonomic concepts into road sign design represents a possible path for enhancing road safety by improving comprehension of these critical communication tools for all

road users.

CRediT authorship contribution statement

Aliyu Mustapha: Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Ahmad Majdi Abdul-Rani:** Conceptualization, Writing – review & editing, Supervision. **Noorhayati Saad:** Visualization, Writing – review & editing, Supervision. **Mazli Mustapha:** Resources, Supervision, Writing – review & editing.

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.

Data availability

No data was used for the research described in the article.

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