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Yunguo Liu, Zizhen Liu, Xuelin Tang & Rang Meng

Effects of Icon Semantic Distance and Cultural Background on Visual Search Efficiency in Vehicle Control Interfaces

Yunguo Liu1, Zizhen Liu1, Xuelin Tang1*, Rang Meng1

1School of Arts, Chongqing University, Chongqing, China

*Corresponding author

Name: Xuelin Tang

Institutional address: No. 55, South University Town Road, Shapingba District, Chongqing, China

Phone: 18273126206

Email: tangxl@cqu.edu.cn

Abstract

With the increasing complexity of in-vehicle human-machine interfaces (HMIs), the visual search efficiency of functional icons has become crucial for driving operations. Existing research has primarily focused on either physical attributes or cognitive characteristics of icons within single cultural contexts or specific scenarios, leaving the interaction between semantic distance and cultural background insufficiently explored. This study employed a 2 (cultural background: Chinese vs. South Asian) × 2 (semantic distance: close vs. remote) mixed factorial design to investigate their effects on visual search efficiency for functional icons in vehicle control interfaces. The results indicated that semantic distance and cultural background each significantly affected distinct efficiency metrics. Specifically, icons with closer semantic distance were associated with better performance in recognition efficiency and faster search times. Cultural background, meanwhile, showed a significant effect on both search efficiency and recognition time. More critically, a significant interaction was observed between semantic distance and cultural background in terms of search time. This research provides empirical support for cross-cultural in-vehicle interface design. It also supplies a set of readily applicable vehicle control interface icon references for Chinese and South Asian automotive brands, and offers a reusable evaluation methodology for global interface design initiatives by Chinese automakers.

Keywords: Cultural Background, Semantic Distance, Visual Search Efficiency, Vehicle control interface, Functional Icons.

1. Introduction

According to data released by the General Administration of Customs, China's automobile exports reached 5.221 million units in 2023, a year-on-year increase of 57.4%, hitting a record high. [1]. This indicates that Chinese automotive brands are encountering challenges in optimizing cross-cultural user experiences during their global expansion. The “Belt and Road” trade volume index released by the Shanghai Shipping Exchange shows that as of 2025, China's trade index with South Asia has risen to 203.12 points, reflecting a 3.5% increase compared to the previous period [2]. In terms of automotive exports, China's export value to major South Asian countries reached approximately 4.68 billion yuan in 2024 [3]. A horizontal comparison with other regions reveals that trade growth in South Asia has significantly outperformed many other regions, underscoring its importance as a key destination for Chinese brands expanding overseas . Existing studies have demonstrated that cultural differences can influence users' comprehension of in-vehicle interface information architecture [4] and their efficiency in recognizing abbreviations for complex functions [5]. This suggests that in high-risk driving scenarios, such cultural disparities may prolong interaction times and pose safety hazards [6]. Therefore, further research on cross-cultural differences in automotive contexts is necessary.

Icons, which are capable of conveying meaningful information rapidly [7][8][9][10], are widely employed in contexts that require efficient information transfer and streamlined communication. Their unique value lies in transcending language barriers, enhancing reading speed [11][12], and optimizing digital interface space to some extent [13]. However, poorly designed icons can easily cause recognition confusion, a problem with particularly severe consequences in driving environments.

As the core component of in-vehicle information systems, human-machine interfaces (HMIs) have grown increasingly complex with system upgrades, leading to a significant rise in interaction difficulty [14]. Research on text, icons, and their interrelationships in display interfaces has shown that graphical symbols have a broader recognition range than text [15]. Among these, cognitive processing difficulty is highest under pure graphical conditions. Nevertheless, users exhibit faster reaction times and higher accuracy with icons that combine graphics and keywords [16][17]. Thus, enabling users to acquire icon-conveyed information more quickly and accurately has become a central focus for researchers. In current in-vehicle HMI studies, researchers have explored the importance of icon design for driving safety and operational efficiency [10][18][19][20]. Existing research primarily revolves around two key directions: one focuses on the impact of physical attributes such as icon size and position on driver performance [18]; the other addresses the role of cognitive characteristics like concreteness [20], similarity [10], and semantic distance in drivers' comprehension and recognition efficiency [19].

Semantic distance is a critical feature determining icon cognitive efficiency, primarily measuring the closeness between an icon's representation and its intended meaning [21]. In other words, for users, a shorter semantic distance corresponds to higher visual search efficiency, while a longer distance results in lower efficiency [22]. Previous studies have often focused on the characteristics of individual icons [20][21]. However, in automotive HMI contexts, icons are typically presented as sets encompassing various driving functions. To maximize driver operational efficiency, each icon in a set must semantically align as closely as possible with users' mental models of the function's graphical representation.

Furthermore, variations in interaction demands exist within in-vehicle interfaces. This is particularly true for high-frequency, high-risk interaction environments such as vehicle control interfaces. As key interfaces supporting rapid operations, vehicle control interfaces impose stricter requirements on the visual search efficiency of icons. Unfortunately, most current research on in-vehicle icons remains confined to generic interface scenarios, lacking in-depth exploration of specific contexts like vehicle control interfaces.

In summary, contemporary icon research has expanded beyond single interface scenarios to encompass diverse fields such as automotive, industrial, medical, and military applications [8][9][13][23]. However, existing studies on in-vehicle icon design primarily address aspects like page layout, size, position, and style [10][18][24]. Two significant gaps remain: first, a lack of investigation into the characteristics of semantic distance and its interactive effects with other factors; second, most studies are based on universal scenarios within single cultural contexts, neglecting cultural background variations in global markets. As international users increasingly adopt Chinese vehicle brands, cultural differences may prolong interaction times in high-risk driving scenarios, thereby introducing potential safety hazards [6]. Therefore, this study employs functional icons from vehicle control interfaces of Chinese automotive brands as experimental vehicles. Through comparative experiments across different cultural backgrounds, it investigates the independent influences and interactive effects of semantic distance and cultural background on icon search efficiency.

2. Related work

2.1. Cognitive Characteristics of Icons

Isherwood et al. proposed that current research on cognitive characteristics affecting icon effectiveness primarily includes familiarity, concreteness, visual complexity, meaningfulness, and semantic distance [25]. Traditional icons typically resemble the objects they represent to emphasize familiarity [26]. Concreteness indicates the degree to which an icon is visually figurative, widely regarded by scholars as one of the most relevant attributes for symbols and icons [24]. Complexity reflects the level of detail in an icon. Concreteness and complexity are often studied jointly by researchers due to their direct relevance to image design. Romain Collaud et al. found that concreteness facilitates icon comprehension and is more readily understood than abstract icons [27]. Meaningfulness represents the semantic meaning users associate with the icon, possessing certain cultural attributes [28].

Semantic distance is employed to measure the gap between the intended meaning and the actual user cognition, serving as a critical feature for determining icon effectiveness. Other icon characteristics, such as familiarity and concreteness, may influence semantic distance. Consequently, semantic distance can act as a comprehensive indicator, integrating the effects of other characteristics. Simultaneously, Zhang et al. found that the semantic distance of icons significantly impacts cognitive performance. Icons with closer semantic distance can better attract user attention, thereby yielding higher cognitive performance [22]. Subsequently, researchers further explored the influence of semantic distance on icon usability. Isherwood et al. investigated the relationship between users' interpretations of icons and the meanings designers intended to convey. They ultimately found that semantic distance is the most crucial factor determining icon usability and established its critical importance when users initially learn icon-function relationships [25].

Furthermore, research has shown that users' efficiency in recognizing the functional semantics of icons is also influenced by other factors. For instance, the layout of icons within an interface influences users' understanding of their semantics [19]. Shen et al. discovered that icon style alters users' recognition and extraction of icon semantics [29]. External factors also impact this recognition. For example, age amplifies the disparity caused by semantic distance during user recognition of functional icons [30][31][32]. Meanwhile, studies on icons in contexts such as medical systems, industry, and automotive cockpits have shown that user requirements for icon semantic distance vary across different task scenarios [7][11][33]. Because it is more readily quantifiable, semantic distance plays a core role in both user icon recognition and designer optimization and iteration. The influence of semantic distance on search and recognition efficiency is not only manifested in the icon's own visual representation [19] but is also dynamically modulated by external factors such as user cognition [34][35] and environmental interference [11]. Consequently, research on semantic distance is gradually shifting from focusing solely on the icon's inherent properties towards incorporating external factors and specific contexts.

Unlike conventional icon design, novel functions such as head-up displays, lacking real-world counterparts, are difficult to express through traditional intentional metaphors. Designers are therefore compelled to employ more abstract representations. Consequently, the difficulty for drivers in searching, recognizing, and using these new functions increases substantially. Icons within the vehicle control interface typically appear as icon sets, characterized by relatively high functional density. As a high-frequency, high-risk interaction zone, the functional icons within the vehicle control interface lack specific research. Therefore, it is necessary to conduct further research on functional icons within the vehicle control interface of automotive digital interfaces, providing a new theoretical reference for driving safety under high functional density.

2.2. Research on Cultural Background Differences in In-Vehicle Interaction

Research has found that different cultural groups exhibit distinct behavioral tendencies and performances during in-vehicle interaction [34]. Wang, Peggy et al. discovered through their study of Chinese and American user behavior with in-vehicle voice systems that users from different cultures approach communication with voice systems differently [35]. Such differences are not confined solely to voice interaction. Olaverri-Monreal et al. found cultural differences among German, American, and Japanese users when utilizing Driver Information Systems (DIS) — a central information hub that consolidates and presents vehicle-related data to the driver, primarily manifested in preferences for and usage of menu structures [4]. Research within Asia is not solely concentrated on East Asia. Khan, Tawhid et al. investigated the usage preferences of British and Indian users for automotive HMIs, highlighting differences in expectations and usage of HMI systems among different groups [36].

A review of cross-cultural research on in-vehicle interaction reveals that current studies predominantly focus on cultural differences between Eastern and Western regions, with limited investigation into differences between other regions. South Asia, as a blue ocean market for Chinese automotive exports, possesses a culture distinctly different from East Asia (to which China belongs) and the European and American cultures that were previously the primary research focus. Do South Asian users exhibit different cognition and usage preferences when interacting with automotive HMIs? This question warrants further research and validation.

2.3. Impact of Icons on Visual Search Efficiency

Research on the influence of icon design on visual search efficiency typically examines one or two icon characteristics. Huang et al. found that beyond traditional comprehensibility and recognizability, icon style and type are also crucial for user recognition and understanding [15]. Scholars have conducted a series of studies on this, with results indicating that three-dimensional (3D) icons outperform two-dimensional (2D) icons in terms of attention allocation and attention capture [29][37]. However, icon representation encompasses more than just dimensionality. It has been confirmed that factors such as icon luminance contrast, color, icon border form, and interface background color saturation also impact user search performance[38][39]. External factors can also interact with icon characteristics. For instance, the overall page layout of icons influences users' visual search efficiency[40]. Furthermore, Chen Ruoyu et al. investigated the differences in preferences for icon styles and actual visual search efficiency among different user groups. Results showed that younger adults exhibited higher visual search efficiency with 3D icons compared to older adults, yet preferred 2D graphics [41]. Not only does age affect visual search efficiency, but gender differences in visual search efficiency have also been observed. Males are often more susceptible to interference from an icon's compositional elements, whereas females tend to be more affected by its metaphorical meaning and the surrounding interface context [42]. Additionally, users may demand higher rigor and precision regarding icons in specialized environments. Jiang Shao et al. substantiated this point. In exploring the impact of visual presentation of industrial icons on search efficiency, they found that visual search efficiency was optimal when icons had a line width of 1.0px, a figure-to-ground area ratio of 50%, and negative polarity [7].

In summary, research gaps persist concerning: (a) the interaction effects of icon semantic distance with other factor, (b) functional icons within vehicle control interfaces of automotive systems, and (c) visual search efficiency in cross-cultural populations. Meanwhile, it has been substantiated that optimizing icons and cognitive processes proves feasible for enhancing visual search efficiency. As visual search and recognition constitute the primary behaviors during driver interaction operations, they hold high value for investigating user visual search efficiency. In this study, we employ visual search tasks and visual recognition tasks to explore the influence of users' cultural background and semantic distance on their perception and recognition of icons.

3. Materials and methods

The study comprised two experiments. The experiment was conducted online and at the Human-Computer Interaction Laboratory of Chongqing University, with approval from the School of Arts Ethics Committee. (Approval document: I20241213-R8). All methods of this study were performed in accordance with the relevant guidelines and regulations (including the Declaration of Helsinki). Informed consent was obtained from all participants.

3.1. Experiment 1

3.1.1. Participant

This study employed random sampling for participant selection. Written informed consent was obtained from all participants before questionnaire distribution to ensure confidentiality and voluntary participation.

Given that the participant's cultural background served as the between-subjects variable in this experiment, a precise definition was required before experimentation. Participants belonging to the Chinese cultural background were defined as users who had long-term residence and upbringing in China and held Chinese nationality. Participants belonging to the South Asian cultural background were defined as users with long-term residence and upbringing in South Asian countries and non-Chinese nationality. To accommodate diverse participants, the questionnaire was available in both Chinese and English. Participants who passed the quality checks received a compensation of 2 CNY each. Additionally, a pilot test with 50 samples was conducted before the formal distribution. Based on pilot test results, revisions were made to wording and functional explanations, and the final revised questionnaire was officially distributed.

Data collection was conducted through professional online survey services (Credamo and Cloud Research) from December 31, 2024, to March 15, 2025. It is important to note that, through the aforementioned multiple channels, the study extensively recruited participants from China and South Asia, including other demographic characteristics such as gender, age, educational background, and other factors, to cover a broader population range and ensure sample diversity.

3.1.2. Materials and Procedure

Icons in this study were sourced from common functions within the vehicle control interfaces of Chinese brand automotive HMIs. A total of 63 functions were collected from the vehicle control interfaces of 13 brands. To ensure representativeness, 11 common functions were selected from these 63 functions, primarily including functions frequently used by current automotive brands, such as window lock, screen cleaning, and sentry mode. Due to high similarity in design style among some icons, redundant similar icons were eliminated. Additional icons were downloaded from the open-source Iconfont platform (iconfont.cn) to ensure that each of the 11 function groups had three representative icons exhibiting distinct differences.

All selected icons underwent secondary processing to standardize elements such as color tone and line width. As most icon elements were composed of irregular geometric shapes, all icons were uniformly positioned within squares of equal size. And textual labels were removed from the composite icon sets.

Prior to conducting Experiment 1, a preliminary experiment was systematically carried out to assess whether differences existed in familiarity with the icon set used in this study between Chinese and South Asian users. The participants in this preliminary experiment were distinct from those in the subsequent Experiment 1, to ensure a clear separation between the phases and to mitigate potential effects of familiarity on the formal experiment. An independent-samples t-test then results indicated no significant difference in overall familiarity with the icon set between Chinese ($n = 188$) and South

Asian (n = 184) participants (t(370) = 1.86, p = .062, Cohen's d = 0.26). The final set of icons used for testing is shown in **Fig 1**.

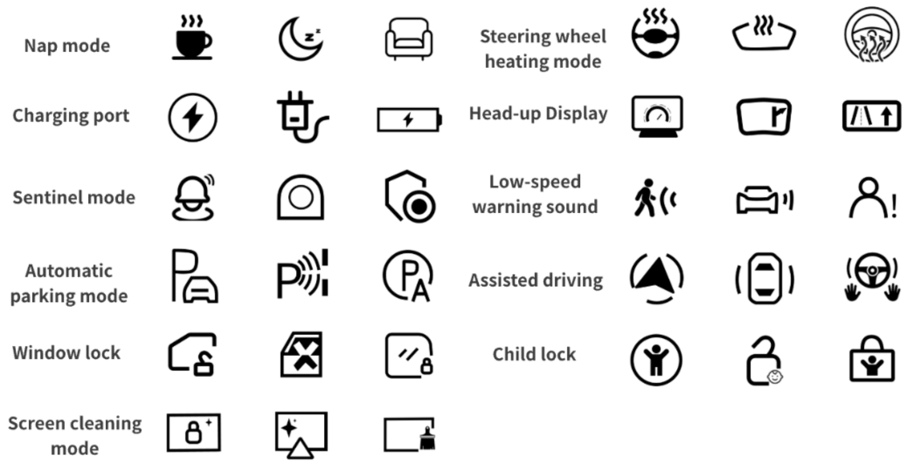


Fig 1. Icons used in Experiment 1

The experiment was conducted using an online questionnaire comprising two main sections: demographic information and icon rating. The demographic section collected data on participant gender, age, nationality, education level, and driving experience. Subsequently, each participant was required to sequentially review explanations of the 11 functions and then rate each of the three icons representing these functions. A score of 1 indicated that the participant believed the icon completely failed to convey the intended meaning of the function and did not evoke an association with the function. Higher scores represented a stronger perceived match between the icon and the function, with a maximum score of 7 points. The highest-rated icon per function was defined as its close semantic distance icon; the lowest-rated as its remote semantic distance icon.

3.2. Experiment 2

The purpose of Experiment 2 was to determine differences in reaction time and comprehension accuracy rates between two semantic distances of icons under two distinct cultural backgrounds: Chinese users and South Asian users.

3.2.1. Participants

Participants for this study were recruited through poster advertisements. Each participant signed a written informed consent form prior to beginning the experiment. A total of 48 individuals participated in the study. The Chinese group consisted of native Chinese students. The South Asian group consisted of international students who originated from and were raised in South Asian countries and were currently pursuing their degrees in China. This sampling approach was pragmatically chosen for accessibility. All participants were right-handed with normal or corrected-to-normal vision and proficient in operating computers and smart devices. Participants had no color blindness or color weakness. Upon completing the experiment, each participant received a remuneration of 50 CNY.

3.2.2. Apparatus

The experiment was conducted under normal lighting conditions in a laboratory at Chongqing University. The experimental procedure was programmed using PsychoPy to present stimuli and record participants' behavioral data. Stimuli were displayed on a 27-inch LCD monitor with a resolution of 1920×1080 and a refresh rate of 60 Hz. Participants performed tasks using a keyboard and mouse, with a viewing distance set at 50 cm from the screen. The visual angle subtended by a single icon was approximately 5.8° × 5.8°. This size was determined with reference to real-world in-vehicle interfaces.

3.2.3. Materials and Procedure

Prior to the formal commencement of the experiment, each participant was provided with a printed copy of the "Experiment Instructions and Task Guide". This document detailed the overall experimental procedure, the types of tasks involved (Learning Task, visual search, and semantic recognition), their respective objectives, and the specific methods for responding. This documentation was designed to ensure that participants provided adequate informed consent and maintained a clear cognitive framework of the tasks throughout the entire session.

To better simulate and accommodate on-screen presentation, the stimulus size in this experiment was set to 50 × 50 mm. Materials for Experiment 2 consisted of icons corresponding to specific semantics derived from the survey analysis of Experiment 1. The designated close-and remote-semantic icons for the two cultural groups are inconsistent, specifically in Sets 3, 5, and 9. The final icons used for testing are shown in **Fig 2**. To account for the impact of variations in icon implementation, we plan to employ mixed-effects models in subsequent experiments, specifying icons as random effects to isolate and control for inherent differences across individual icon designs.

Fig 2. Icons used in Experiment 2

This study consisted of three tasks: a learning task, a visual search task, and a visual recognition task. All three experimental tasks were completed sequentially within a single day. The entire experiment lasted approximately 0.5 hours, with 5-minute breaks between tasks. Prior to the formal tasks, participants were required to independently complete a procedural test. This test simulated the key components of the main experiment—comprising two trials each from the learning, visual search, and semantic recognition phases—while utilizing textual and iconic materials entirely distinct from those in the formal experiment. This test served a dual verification purpose: first, to evaluate participants' competence in operating computer devices, specifically their ability to accurately use the mouse for selection and the keyboard for responses; second, to confirm their familiarity with the complete experimental procedure, demonstrated by their capacity to independently navigate the multi-stage tasks without guidance. The test did not evaluate the correctness of choices but required successful completion of the entire workflow. Passing this test served as an objective criterion for satisfying both operational skill and procedural comprehension requirements, thus constituting a prerequisite for participation in the formal experiment. Furthermore, to ensure that participants from different cultural backgrounds would not be affected by textual translation in their understanding of the experimental materials, all textual content underwent a rigorous translation process: initial translation by a bilingual researcher was followed by independent back-translation by another researcher unfamiliar with the original text. The two versions were then compared and refined until semantic consistency was achieved.

3.2.3.1. Learning Task

The purpose of this initial phase was to ensure that all participants established a consistent and accurate understanding of the semantic concepts of the automotive functions before they encountered any visual icons.

Fig 3 shows an example of the learning task flowchart. Participants were sequentially presented with the names and detailed textual descriptions of the 11 functions. Each trial began with a 1000 ms fixation cross, followed by the unlimited-duration presentation of a function's name alongside its explanatory text. The key aspect of this phase was the complete absence of any icons throughout the entire procedure, with only functional terms alongside their corresponding explanations being displayed. Participants advanced to the next function by mouse click only after confirming their comprehension. The stimulus presentation order was randomized for each participant. This stage was designed to help participants establish a consistent conceptual understanding of each function, thereby ensuring that any performance differences observed in subsequent tasks could be more reliably attributed to variations in icon comprehension rather than functional unfamiliarity. Following the learning phase, a learning assessment was administered wherein participants were required to verbally articulate the meaning of each function to the experimenter, thereby demonstrating their comprehension. All participants were required to achieve 100% accuracy in this assessment before proceeding to subsequent experimental phases.

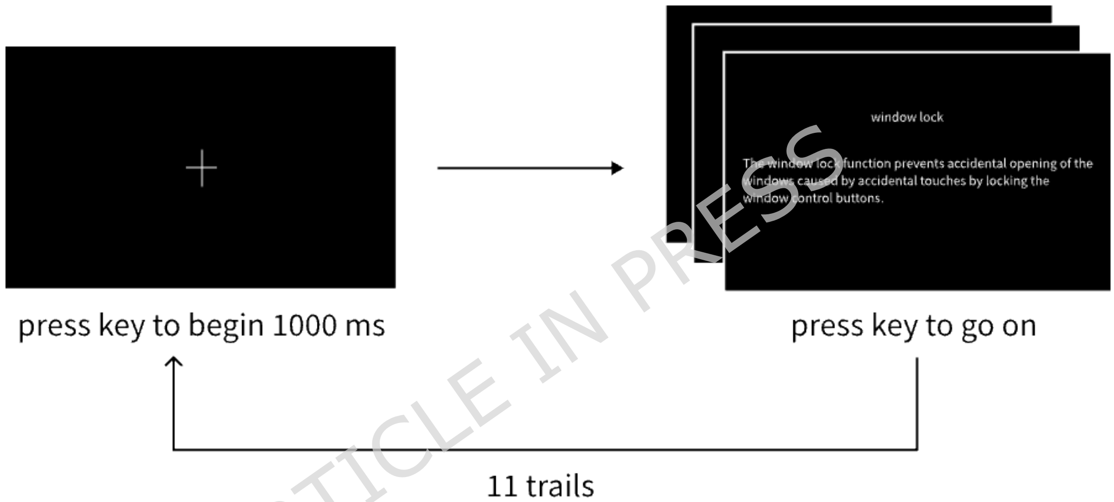


Fig 3. Experimental sequence of the learning task

3.2.3.2. Visual Search Task

Fig 4 shows an example flowchart for the visual search task. The formal experiment consisted of four phases: In the first phase, a white fixation cross "+" with a black background and white text appeared at the center of the screen for 1000 ms and then disappeared; participants did not need to take action. In the second phase, a semantic word was displayed at the center of the screen. Participants had 2000 ms to fully understand and memorize the semantic word, after which the word disappeared. In the third phase, a blank screen was presented to participants for 1000 ms to eliminate the mental impression of the displayed semantic word. Then, nine icons appeared at the center of the screen, including one target icon and eight distractor icons. Distractor icons were randomly selected from the icon pools of the remaining ten functions. To ensure that differences in search difficulty originated from the target icon itself, we controlled the distractor set in each trial such that four distractors were "close semantic distance" icons, and the other four were "remote semantic distance" icons.

The task comprised a total of 25 trials. Twenty-two of these were core trials, where, for each function, the two icons defined as "close-semantic-distance" and "remote-semantic-distance" for the participant's cultural group (based on the results of Experiment 1) each served as the target once. The remaining three trials were filler trials, data from these trials were excluded from the final statistical analysis. Participants were required to find the target icon matching the semantic word as quickly as possible. After finding the target icon, participants needed to move the mouse cursor over it and click the mouse button. The dependent variables were the accuracy of participants' responses and the response time measured from the appearance of the icons to the mouse click.

Icons were arranged in a grid pattern, consistent with the display of icons in actual in-vehicle HMI control interfaces. The criteria for random icon display on the page were as follows: (a) close semantic distance icons and remote semantic distance icons of the same function did not appear simultaneously; (b) among the nine icons displayed on the same page, four were close semantic distance icons, four were remote semantic distance icons, and one was a randomly selected icon from the remaining unselected functional icons. No feedback was provided during the experiment.

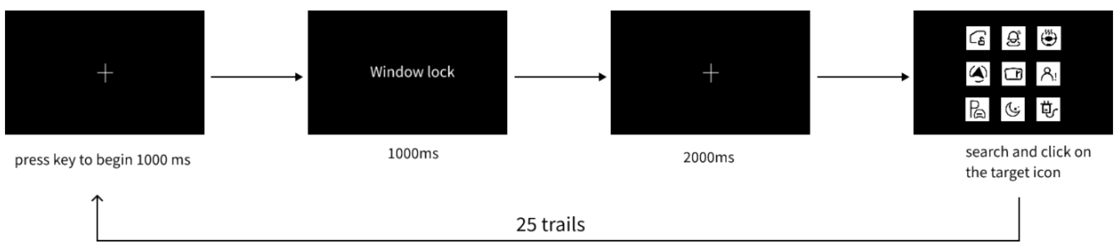


Fig 4. Experimental sequence of the visual search task

3.2.3.3. Semantic Recognition Task

Fig 5 shows an example of the semantic recognition task flowchart. Each trial began with a 1000 ms fixation period for participants. Subsequently, participants saw a row of five randomly selected icons in the center of the screen for 6000 ms. Then, a 1000 ms blank screen followed. Participants needed to remember as many icons as possible during this period. Afterwards, they saw a semantic word and had to judge whether the icon matching that semantic word had appeared in the previous row of icons. If the icon had appeared, participants were instructed to press “J”; otherwise, they were instructed to press “F”. The dependent variables were the accuracy of participants' responses and the response time measured from the appearance of the semantic word to pressing the “F” or “J” key.

This task consisted of 36 trials. Twenty-five of these trials were target-present trials. Among these 25 trials, 22 were core trials, whose target icon selection matched that of the visual search task, while the other 3 were filler trials. The remaining 11 trials were target-absent trials. Only the data from these 22 core target-present trials were utilized in the analysis. In one-third of these trials, the target icon was absent from the memory sequence to prevent participants from developing a habitual guessing strategy. The rules for random selection of icons on the recognition display page were as follows: (a) among the five icons displayed on the same page, two were close semantic distance icons, two were remote semantic distance icons, and one was a randomly selected icon from the remaining unselected functional icons; (b) in one-third of the trials, the target icon did not appear on the recognition interface.

The icons presented to each participant in this task were randomized. Additionally, to maintain consistency with the procedure of the visual search task, no feedback was provided during this task.

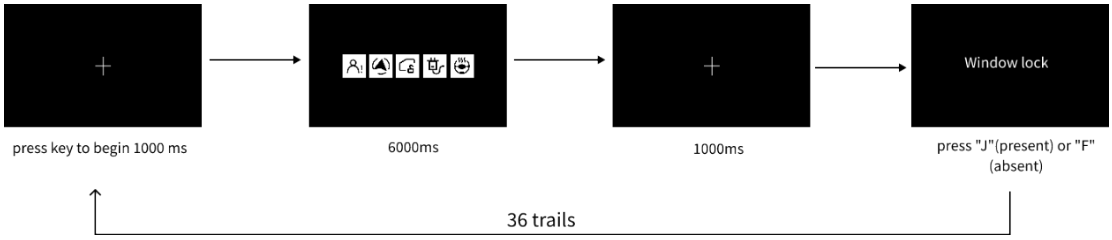


Fig 5. Experimental sequence of the visual recognition task

4. Results

4.1. Experiment 1

A total of 371 questionnaires were collected (186 from Chinese users, 185 from South Asian users). After excluding 32 invalid questionnaires that failed attention checks, 339 valid questionnaires were retained. Participant demographic characteristics are as follows (

Table 1.): females accounted for 57.2%, males 42.8%; the primary age group was 18-30 years, while those aged 31 and above accounted for 36.5%; 72.8% held a bachelor's degree or higher; participants with >5 years of driving experience constituted the largest proportion, though those with limited driving experience also participated.

Table 1.

Participant Demographic Characteristics

Category		n	%
Gender	Male	145	42.8%
	Female	194	57.2%
Age	<18 years	3	0.9%
	18-25 years	125	36.9%
	26-30 years	87	25.7%
	31-40 years	54	15.9%
	41-50 years	37	10.9%
	51-60 years	17	5.0%
	>60 years	16	4.7%
Education	Junior high school or lower	1	0.3%
	High school/Technical	54	15.9%
	Associate degree	37	10.9%
	Bachelor's degree	155	45.7%
	Master's degree or higher	92	27.1%
Nationality	Chinese	169	49.9%

	South Asian	170	50.1%
Driving Experience	No driver's license	44	13%
	License holder, rarely drives	86	25.4%
	<1 year	16	4.7%
	1-3 years	41	12.1%
	3-5 years	17	5%
	>5 years	135	39.8%

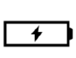
Prior to the main analysis, we assessed the reliability of the icon ratings across the 33 icons to ensure data consistency; the results indicated a Cronbach's Alpha of .782. Additionally, the Intraclass Correlation Coefficient (ICC) of .717 for average measures, suggesting good reliability for aggregating individual ratings into mean scores per icon.

To examine the effects of cultural background and icons on user ratings, descriptive statistics were first calculated for the participants' ratings of the 11 functional icon sets. The means and standard deviations for the two participant groups are presented in

Table 2.

Table 2.
Mean Ratings and Standard Deviations for Icon Sets by Cultural Background

Icon Set	Icon Group	Chinese Group (SD)	South Asian Group (SD)	Total (SD)
1 (Steering wheel heating mode)	 1	5.42 (1.39)	5.51 (1.42)	5.47 (1.41)
	 2	4.57 (1.60)	4.51 (1.62)	4.54 (1.61)
	 3	2.77 (1.72)	1.91 (1.39)	2.34 (1.62)
2 (Screen cleaning mode)	 1	3.50 (1.68)	2.94 (1.53)	3.22 (1.63)
	 2	5.17 (1.84)	4.81 (2.13)	4.99 (2.00)
	 3	4.06 (1.73)	3.76 (1.92)	3.91 (1.83)
3 (Automatic parking mode)	 1	5.12 (1.76)	4.03 (1.63)	4.58 (1.78)
	 2	4.24 (1.80)	4.77 (1.72)	4.50 (1.78)

	 3	3.67 (1.91)	3.36 (2.01)	3.52 (1.97)
4 (Charging port)	 1	4.83 (1.80)	4.41 (1.73)	4.62 (1.77)
	 2	5.53 (1.65)	6.03 (1.21)	5.78 (1.47)
	 3	3.93 (1.63)	3.71 (1.73)	3.82 (1.68)
5 (Head-up display)	 1	4.19 (1.78)	4.72 (1.70)	4.46 (1.76)
	 2	3.74 (1.66)	3.24 (1.76)	3.49 (1.73)
	 3	4.73 (1.83)	3.88 (1.77)	4.30 (1.84)
6 (Child lock)	 1	6.02 (1.23)	5.84 (1.44)	5.93 (1.34)
	 2	4.59 (1.54)	4.79 (1.47)	4.69 (1.51)
	 3	3.00 (1.76)	2.28 (1.27)	2.64 (1.58)
7 (Low-speed warning sound)	 1	3.46 (1.65)	2.54 (1.48)	2.99 (1.63)
	 2	5.38 (1.55)	5.16 (1.60)	5.27 (1.58)
	 3	4.57 (1.80)	4.33 (1.66)	4.45 (1.74)
8 (Window lock)	 1	4.90 (1.75)	5.49 (1.48)	5.19 (1.64)
	 2	3.50 (1.78)	3.14 (1.90)	3.32 (1.85)
	 3	5.45 (1.56)	4.16 (1.70)	4.81 (1.75)
9 (Nap mode)	 1	5.25 (1.81)	2.42 (1.72)	3.83 (2.26)
	 2	3.83 (2.26)	3.54 (1.45)	4.04 (1.63)
	 3	4.07 (1.92)	5.88 (1.33)	4.98 (1.88)
10 (Assisted driving)	 1	3.43 (1.73)	2.84 (1.61)	3.13 (1.70)
	 2	3.95 (1.64)	3.29 (1.42)	3.62 (1.57)
	 3	5.59 (1.62)	6.02 (1.24)	5.80 (1.46)

11 (Sentinel mode)	 1	4.00 (1.54)	4.11 (1.58)	4.05 (1.56)
	 2	2.93 (1.64)	2.18 (1.40)	2.56 (1.57)
	 3	5.65 (1.51)	4.81 (1.69)	5.23 (1.65)

The overall semantic cognitive rating of Chinese participants for all icons (M=4.42, SD=1.89) is higher than that of South Asian participants (M = 4.07, SD = 1.98). A mixed-design analysis of variance (ANOVA) was subsequently conducted to further examine these effects, indicating statistically significant differences in the overall evaluation of most icon sets between Chinese and South Asian participants (**Table 3.**). Furthermore, a significant main effect of icon visual representations was observed across all 11 icon sets (all $p < .001$), with effect sizes (partial η^2) ranging from .075 to .557, confirming significant differences in semantic cognitive rating among the three icons within each set.

More importantly, to interpret these interaction effects, we conducted simple effects analyses. Specifically, pairwise comparisons among the three icons were performed separately within the Chinese and South Asian groups, with the Bonferroni correction applied for multiple comparisons. The analysis revealed significant Icon × Culture interaction effects. Statistically significant interactions were observed in 10 out of the 11 icon sets (all $p < .05$), accounting for 91% of the total.

Table 3.

Results of the Mixed-Design ANOVA on Icon Ratings

Icon Set	Effect Type	*Df*	*Df*.res	*F*	*p*	Effect Size (partial η^2)
1 (Steering wheel heating mode)	Icon Main Effect	1.95	657.56	355.02	< .001	.513
	Culture Main Effect	1	337	9.38	.002	.027
	Icon × Culture Interaction	1.95	657.56	9.08	< .001	.026
2 (Screen cleaning mode)	Icon Main Effect	1.80	604.76	69.90	< .001	.172
	Culture Main Effect	1	337	19.15	< .001	.054
	Icon × Culture Interaction	1.80	604.76	0.43	.653	.001
3 (Automatic parking mode)	Icon Main Effect	2	674	31.60	< .001	.086
	Culture Main Effect	1	337	9.07	.003	.026

	Icon × Culture Interaction	2	674	15.04	< .001	.043
4 (Charging port)	Icon Main Effect	2	674	123.07	< .001	.267
	Culture Main Effect	1	337	0.22	.643	.001
	Icon × Culture Interaction	2	674	7.57	.001	.022
5 (Head-up display)	Icon Main Effect	1.89	637.42	27.27	< .001	.075
	Culture Main Effect	1	337	7.48	.007	.022
	Icon × Culture Interaction	1.89	637.42	13.01	< .001	.037
6 (Child lock)	Icon Main Effect	1.93	650.26	423.43	< .001	.557
	Culture Main Effect	1	337	7.08	.008	.021
	Icon × Culture Interaction	1.93	650.26	8.09	< .001	.023
7 (Low-speed warning sound)	Icon Main Effect	2	674	168.16	< .001	.333
	Culture Main Effect	1	337	20.64	< .001	.058
	Icon × Culture Interaction	2	674	5.05	.007	.015
8 (Window lock)	Icon Main Effect	2	674	102.24	< .001	.233
	Culture Main Effect	1	337	14.88	< .001	.042
	Icon × Culture Interaction	2	674	22.82	< .001	.063
9 (Nap mode)	Icon Main Effect	1.91	644.34	41.49	< .001	.110
	Culture Main Effect	1	337	52.87	< .001	.136
	Icon × Culture Interaction	1.9	644.34	152.64	< .001	.312
10 (Assisted driving)	Icon Main Effect	1.95	657.84	283.74	< .001	.457
	Culture Main Effect	1	337	7.87	.005	.023
	Icon × Culture Interaction	1.95	657.84	13.08	< .001	.037
11 (Sentinel mode)	Icon Main Effect	1.94	653.28	242.28	< .001	.418
	Culture Main Effect	1	337	27.22	< .001	.075
	Icon × Culture Interaction	1.94	653.28	9.21	< .001	.027

The first type includes icon sets where Chinese and South Asian participants consistently assigned the highest and lowest ratings to the same icons, yet South Asian users provided more extreme ratings for these icons. For Icon Set 1 (steering wheel heating), a significant interaction effect was observed (F(1.95, 657.56) = 9.08, $p < .001$, partial $\eta^2 = .026$). Although both user groups shared an identical rating hierarchy for the icons within the set—icon 1 > icon 2 > icon 3 (all $p < .001$)—South Asian users assigned a significantly lower rating to icon 3, which was perceived as having the poorest function-semantic match (Mean Difference = 0.863, $p < .001$). In Icon Set 10 (assisted driving) (F(1.95, 657.84) = 13.08, $p < .001$, partial $\eta^2 = .037$), both groups exhibited the same rating order: icon 3 > icon 2 > icon 1 (all $p \leq .021$). South Asian users gave a significantly lower rating to icon 1 (Mean Difference = 0.591, p = .001) and a significantly higher rating to icon 3 (Mean Difference = -0.432, p = .006). A similar pattern was observed in Icon Set 11 (sentry mode) (F(1.94, 653.28) = 9.21, $p < .001$, partial $\eta^2 = .027$), where consensus existed on the hierarchy of icon 3 > icon 1 > icon 2 (all $p \leq .048$), but South Asian users rated icon 2 significantly lower than Chinese users (Mean Difference = 0.753, $p < .001$). This aforementioned phenomenon was also observed in Icon Set 4 (Charging port), Set 6 (Child lock), and Set 7 (Low-speed warning sound).

The second type comprises icon sets where Chinese and South Asian participants disagreed on which specific icons received the highest and lowest ratings. For Icon Set 3 (automatic parking) (F(1.98, 666.74) = 15.04, $p < .001$, partial $\eta^2 = .043$). Chinese users demonstrated the hierarchy of icon 1 > icon 2 > icon 3 (all $p \leq .031$), whereas South Asian users exhibited the order of icon 2 > icon 1 > icon 3 (all $p \leq .006$). Analysis confirmed that Chinese users rated icon 1 as significantly more matching (Mean Difference = 1.095, $p < .001$), whereas South Asian users showed a stronger preference for icon 2 (Mean Difference = -0.534, $p = .006$). Similarly, in Icon Set 5 (head-up display) (F(1.89, 637.42) = 13.01, $p < .001$, partial $\eta^2 = .037$), the rating hierarchy for Chinese users was icon 3 > icon 1 > icon 2 (all $p \leq .045$), contrasting with the hierarchy of icon 1 > icon 3 > icon 2 (all $p \leq .004$) for South Asian users. Consequently, Chinese users gave a significantly higher rating to icon 3 (Mean Difference = 0.845, $p < .001$), while South Asian users assigned a significantly higher rating to icon 1 (Mean Difference = -0.534, $p = .005$). Similarly, the aforementioned phenomenon was also observed in Icon Set 8 (Window lock).

Notably, in Icon Set 9 (nap mode) (F(1.91, 644.34) = 152.64, $p < .001$, partial $\eta^2 = .312$), the ratings given by Chinese and South Asian participants were directly opposite: the icon rated highest by one group was rated lowest by the other. Chinese users strongly favored icon 1 (icon 1 > icon 2 >

icon 3, all $p \leq .026$), whereas South Asian users strongly preferred icon 3 (icon 3 > icon 2 > icon 1, all $p < .001$).

In Experiment 1, we collected rating data for 11 sets of in-vehicle functional icons from Chinese and South Asian cultural groups through questionnaire surveys. Based on this dataset, the icon receiving the highest rating within each set was classified as the close-semantic-distance icon, representing the visual representation deemed most representative of the function. Conversely, the icon receiving the lowest rating was classified as the remote-semantic-distance icon, reflecting a weaker perceived correspondence between its visual representation and the intended function. This methodological approach translated differences in icon visual representations into an operationalized and quantifiable measure of semantic distance, thereby providing crucial experimental materials for the visual search tasks in Experiment 2.

4.2. Experiment 2

To ensure the reliability of data analysis, reaction time data from the visual search and recognition tasks were preprocessed. Data from participants who did not complete the experiment were first excluded. Abnormal data were then cleaned according to the following criteria: (1) trials with reaction times shorter than 200 ms were considered anticipatory and removed; (2) the Median Absolute Deviation (MAD) was used to identify abnormal delays—for each participant, trials with reaction times beyond ±2.5 MAD from their median were recorded as outliers. Following this procedure, 0.9% of trials were excluded from the visual search task and 0.1% from the recognition task. All analyses were conducted using the cleaned dataset. For the analysis of reaction times—namely, search time and recognition time—data were further restricted to correct-response trials to purely reflect semantic cognitive processing speed. In contrast, analyses of accuracy rates (i.e., search accuracy and recognition accuracy) were calculated based on all trials in the cleaned dataset, including both correct and incorrect responses.

To control for individual differences among participants and the potential impact of partially different icon stimuli on the two groups of subjects identified in Experiment 1, mixed-effects models were employed to analyze the data from the visual search and recognition tasks. Reaction time data were analyzed using Linear Mixed Models (LMMs), and accuracy data were analyzed using Generalized Linear Mixed Models (GLMMs). All analyses were performed in IBM SPSS Statistics using the Satterthwaite approximation for degrees of freedom. All models included Cultural Background and Semantic Distance as well as their interaction as fixed effects, with random intercepts for Participant and Icon. For the LMMs on search and recognize time data, we additionally computed the marginal and conditional R^2. These calculations were performed using the r.squaredGLMM function from the MuMIn package in R[43]. We also tested models incorporating random slopes for semantic distance at the participant level. However, these more complex models did not converge, and their AIC and BIC values indicated poorer fit compared to the random-intercept model. Therefore, we report the results from the more parsimonious random-intercept model. The descriptive statistics for the visual search and semantic recognition tasks—including means, standard deviations, and numbers of valid trials—have been organized by cultural background and semantic distance, and are available in Supplementary Table S1 through Supplementary Table S4. This section presents the results of inferential statistical analyses based on LMMs and GLMMs.

4.2.1. Visual Search

Analysis of reaction times from correct trials revealed that the results of the LMM analysis (**Table 4.**) revealed a significant main effect of Cultural Background on Search Time ($F(1, 44.78) = 6.38$, p

$= .015$, $\eta^2 = .13$). The average search time for Chinese participants was significantly shorter than that for South Asian participants. Concurrently, Semantic Distance also demonstrated a significant main effect on Search Time ($F(1, 733.99) = 26.88$, $p < .001$, $\eta^2 = .04$), with icons of close semantic distance associated with shorter search times compared to those of remote semantic distance. Furthermore, a significant interaction was observed between Cultural Background and Semantic Distance ($F(1, 733.99) = 9.95$, $p = .002$, $\eta^2 = .01$). Simple effect analyses indicated that this interaction was primarily driven by the South Asian participant group. For South Asian participants, an increase in Semantic Distance led to a significant prolongation of Search Time ($b = 3.71$, $p < .001$); whereas for Chinese participants, the change in Semantic Distance also resulted in an increase in search time, but the effect was relatively small and not significant ($b = .90$, $p = .13$). The interaction pattern between Cultural Background and Semantic Distance on search time is shown in **Fig 6**. This result demonstrates that the negative impact of Semantic Distance on search efficiency is more pronounced among users from South Asian cultural backgrounds. The marginal R^2 for the visual search time model was .06, and the conditional R^2 was .3.

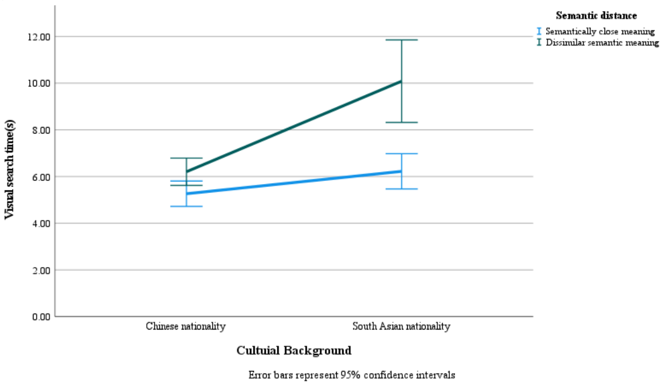


Fig 6. Visual search time for icons of close and remote semantic distance across cultural backgrounds

The GLMM analysis revealed a significant main effect of Cultural Background on Search Accuracy ($F(1, 43) = 21.05$, $p < .001$). Chinese participants demonstrated significantly higher Search

Accuracy compared to South Asian participants. Specifically, the odds of a correct search were 2.4 times higher for Chinese participants than for South Asian participants (OR = 2.40 [1.40, 4.13]). The analysis demonstrated that semantic distance did not exert a significant main effect on search accuracy (F(1, 1051) = 3.70, p = .055, OR = 1.17); and that the interaction between cultural background and semantic distance was also non-significant. (F(1, 1051) = .957, p = .328, OR = 1.38).

The interaction pattern for visual search accuracy is shown in **Fig 7**. Two principal trends are observable. First, Chinese participants consistently demonstrated higher accuracy than South Asian participants across both semantic distance conditions, corroborating the significant main effect of cultural background. In both cultural groups, although icons with closer semantic distance yielded slightly higher accuracy rates than those with remote semantic distance, the difference did not reach statistical significance.

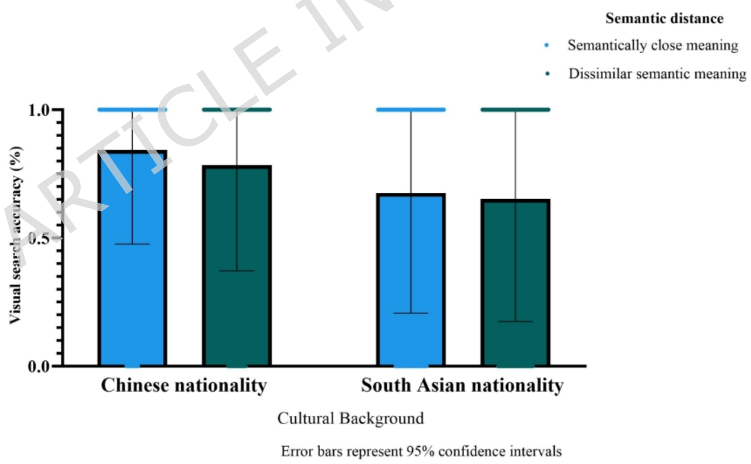


Fig 7. Visual search accuracy for icons of close and remote semantic distance across cultural backgrounds

Table 4.

Effects of Cultural Background and Semantic Distance on the Visual Search Task

Dependent Variable	Predictor	*F-value*	Numerator *df*	Denominator *df*	*p*	Effect Size (η^2) / Odds Ratio (OR)
Search Time	Cultural Background	6.38	1	44.78	.015	.13
	Semantic Distance	26.88	1	733.99	<.001	.04
	Cultural background × Semantic Distance	9.95	1	733.99	.002	.01

Dependent Variable	Predictor	*F-value*	Numerator *df*	Denominator *df*	*p*	Effect Size (η^2) / Odds Ratio (OR)
Search Accuracy	Cultural Background	21.05	1	43	<.001	OR = 2.40 [1.40, 4.13]
	Semantic Distance	3.70	1	1051	.055	OR = 1.17 [0.77, 1.77]
	Cultural background × Semantic Distance	0.96	1	1051	.328	OR = 1.38 [0.72, 2.62]

4.2.2. Visual Recognition

Analysis of reaction times from correct trials revealed that the LMM analysis (Table 5) revealed that Cultural Background exerted a significant effect on Recognition Time ($F(1, 682.71) = 16.78$, $p < .001$, $\eta^2 = .02$), with Chinese participants recognizing icons faster than South Asian participants. The main effect of Semantic Distance was also significant ($F(1, 688.64) = 6.79$, $p = .009$, $\eta^2 = .01$), specifically, recognition time for icons with close semantic distance was significantly shorter than for those with remote semantic distance. However, the interaction between Cultural Background and Semantic Distance was not statistically significant ($F(1, 681.96) = 3.44$, $p = .064$, $\eta^2 = .01$). For the recognition time model, the marginal R^2 was .03 and the conditional R^2 was .08.

The GLMM results (Table 5.) showed no statistically significant main effect of Cultural Background on Recognition Accuracy ($F(1, 1050) = 0.35$, $p = .554$, OR = .80). In contrast, Semantic Distance demonstrated significant main effect ($F(1, 1050) = 38.25$, $p < .001$), with close-semantic-distance icons being 2.76 times more likely to be correctly recognized than remote-semantic-distance icons (OR = 2.76 [1.87, 4.08]). Furthermore, the interaction between these two factors was not statistically significant ($F(1, 1050) = 1.04$, $p = .309$, OR = .75). As illustrated in **Error! Reference source not found.**, recognition accuracy was consistently higher for close-semantic-distance icons compared to their remote-semantic-distance counterparts, regardless of Cultural Background.

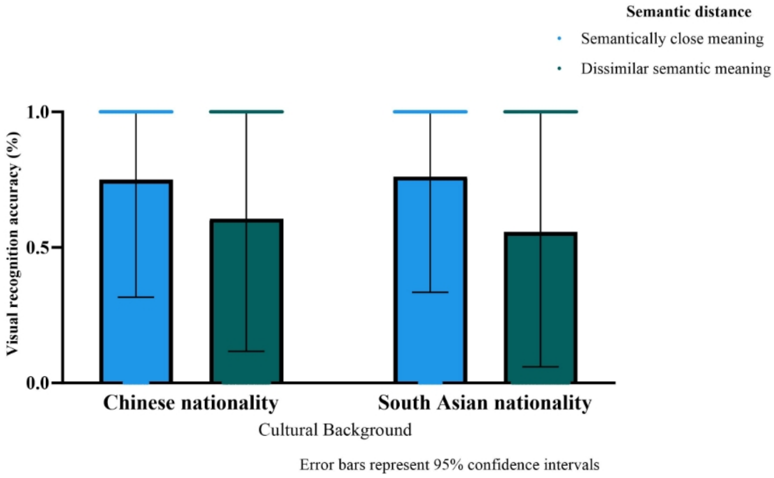


Fig 8. Semantic recognition accuracy for icons of close and remote semantic distance across cultural backgrounds

Table 5.

Effects of Cultural Background and Semantic Distance on the Visual Recognition Task

Dependent Variable	Predictor	*F-value*	Numerator *df*	Denominator *df*	*p*	Effect Size (η^2) / Odds Ratio (OR)
Recognition Time	Cultural Background	16.78	1	682.71	<.001	.02
	Semantic Distance	6.79	1	688.64	.009	.01
	Cultural background × Semantic Distance	3.44	1	681.96	.064	.01
Recognition Accuracy	Cultural Background	0.35	1	1050	.554	OR = 1.25 [0.87, 1.80]
	Semantic Distance	38.25	1	1050	<.001	OR = 2.76 [1.87, 4.08]
	Cultural background × Semantic Distance	1.04	1	1050	.309	OR = 0.75 [0.43, 1.30]

5. Discussion

Driven by the expanding export volume of Chinese automobiles, users from diverse cultural backgrounds are increasingly adopting Chinese-brand vehicles. Understanding whether differences exist in how users from different cultures perceive icon semantics is crucial for enhancing the usability efficiency of Chinese-brand cars across cultural groups. Therefore, this study investigates functional icons from Chinese automotive brand vehicle control interfaces through visual search efficiency experiments, exploring the potential effects of icon semantic distance and users' cultural background. The results reveal that semantic distance similarly influences user search efficiency for automotive-specific functional icons, while users' cultural background and its interaction with semantic distance were further identified to impact search efficiency in certain aspects.

5.1.Cultural Influence on Semantic Distance Perception

Experiment 1 aimed to explore cognitive differences in semantic distance among users from different cultural backgrounds regarding the design of functional icons for an in-vehicle control interface, thereby screening materials for subsequent experiments. Participants were required to rate three icons corresponding to the same function on a 1–7 scale after reading their functional description. Results indicated that the overall icon ratings from the Chinese participant group were significantly higher than those from the South Asian group. These results demonstrate that, compared to South Asian users, Chinese users perceive a closer semantic distance to the current icon set, indicating a shorter psychological distance between the icons and their functional concepts.

Further analysis revealed significant interaction effects between cultural background and icon design across most icon sets. For Sets 1 (steering wheel heating), 4 (Charging port), 6 (Child lock), 7 (Low-speed warning sound), 10 (assisted driving), and 11 (sentry mode), while both cultural groups demonstrated identical perceptions regarding which icons represented close versus remote semantic distances, South Asian participants provided more polarized ratings than their Chinese counterparts for both the most and least semantically appropriate icons. In Sets 3 (automatic parking), 5 (head-up display) and 8 (Window lock), although both groups consistently identified the same icon as the least semantically appropriate, they diverged in their selection of the most appropriate representation. This pattern suggests that icons with closer semantic distances may require more nuanced cultural adaptation in their design.

Notably, Set 9 (nap mode) revealed a complete reversal in ratings between the two cultural groups: the icon rated as most semantically appropriate by Chinese participants was evaluated as the least appropriate by South Asian participants. This finding underscores that for functions with straightforward semantics but culturally dependent visual representations, such as nap mode, more meticulous cultural adaptation in icon design becomes particularly crucial.

In conclusion, cultural background independently and significantly influences users' visual search efficiency during the semantic cognitive process. Therefore, implementing culture-specific adaptive design for icons is essential for enhancing user efficiency in automotive contexts, while simultaneously supporting the global expansion of Chinese automotive brands. However, it should be noted that although the preliminary familiarity test revealed no statistically significant differences between groups ($p = .062$), Chinese participants consistently demonstrated higher mean familiarity scores. Concurrently, in the ratings of Experiment 1, Chinese participants also provided overall higher scores compared to their South Asian counterparts. These observations collectively suggest that familiarity or other latent factors may partially account for the observed differences—a possibility that warrants careful consideration in future investigations.

It is important to note that the classification of an icon as having “close” or “remote” semantic distance in this study was not based on an inherent property of the icon itself, but rather on the perceptions and ratings provided by each cultural group. This relative, culturally-grounded definition formed the precise basis for constructing the “close-semantic-distance” and “remote-semantic-distance” materials used in Experiment 2.

5.2. Impact on Visual Search and Recognition Tasks

Experiment 2 employed both visual search and semantic recognition tasks to assess how semantic distance and cultural background influence users' cognitive behavior. The results demonstrated significant main effects of semantic distance on search time, recognition time, and recognition accuracy: icons with closer semantic distance consistently improved these performance metrics. In contrast, the effect on search accuracy did not reach statistical significance. This pattern indicates that the influence of semantic distance varies across different cognitive processing stages.

When examining the influence of cultural background on users' semantic cognition, we found significant main effects of cultural background on search time, search accuracy, and recognition time. However, its impact on recognition accuracy did not reach statistical significance. These findings demonstrate that cultural differences significantly influence user efficiency when interacting with automotive feature icons. Participants from different cultural backgrounds demonstrated varied levels of efficiency when using automotive feature icons.

Notably, our investigation further explored the interaction effects between semantic distance and cultural background. Significant interactions were observed for search time. Simple effects analysis revealed that South Asian participants' search time was more substantially affected by variations in semantic distance compared to their Chinese counterparts. When processing remote-semantic-distance icons, South Asian users exhibited a sharp increase in search time, whereas Chinese users remained relatively unaffected by such icons. This pattern may suggest that users encounter a greater cognitive burden when processing remote-semantic-distance icons within non-native cultural design contexts. Consequently, optimizing semantic distance for target cultural users becomes particularly crucial during the global expansion of Chinese automotive brands. Furthermore, consideration should be given to whether Chinese participants' faster processing of remote-semantic-distance icons might be attributed to their potentially higher familiarity with the icon set—a factor warranting focused investigation in subsequent research.

5.3. Practical Implications

Therefore, a culturally neutral "one-icon-fits-all" solution is not viable for global in-vehicle interfaces. Our findings demonstrate that icon semantic distance is not a universal property but one that varies dynamically across cultural contexts. Consequently, the culturally adaptive design of icons is paramount before launching products in target markets.

This study provides icon recommendations better suited for users in both the Chinese and South Asian markets, serving as a valuable reference for automotive brands. Furthermore, the experiments confirm that remote-semantic-distance icons substantially degrade user efficiency. Therefore, when conducting culturally adaptive design for icons, automotive brands should prioritize optimizing those with larger semantic gaps. Special attention should also be given to icons for which Chinese and South Asian groups show markedly different semantic distance ratings and opposing near-far categorization, as targeted optimization in these cases can substantially improve user efficiency.

Additionally, this research establishes a replicable method combining subjective questionnaire ratings with objective behavioral data analysis. This approach can be utilized by automotive design teams for both cultural adaptation of existing icons and cultural validation of new icon designs. However, caution should be exercised when extrapolating these findings to high-reliability domains like aerospace, where system interfaces are often constrained by stringent international standards and established operational conventions.

5.4. Limitations and Future Work

This study has several limitations: (a) participant diversity: The South Asian cohort in

Experiment 2 was exclusively composed of international students residing in China. While these individuals possessed deeply embedded South Asian cultural backgrounds, their extended immersion in the Chinese cultural milieu may have facilitated certain degrees of acculturation. Thus, future investigations ought to incorporate more diversified samples—encompassing individuals with varied occupational backgrounds and no prior exposure to Chinese culture—to establish the broader generalizability of these findings. (b) Scenario difference: The experiment was conducted in a static laboratory setting, which did not replicate the cognitive load, time pressure, and dynamic visual environment of real-world driving. This implies that while our results clarify the fundamental effects of icon semantic distance and cultural background on cognitive efficiency, direct extrapolation of these findings to actual driving scenarios requires caution. (c) Control of Potential Confounding Variables: Although we standardized basic visual properties of the icons (e.g., size, line width) and confirmed no significant difference in overall familiarity with the icon set between the two cultural groups, we did not systematically measure or control for the complex attributes, such as the familiarity of individual icons. These attributes may have influenced participant task performance.

Based on these limitations, future research could: (1) recruit participants from different professions within their native cultural environments to validate and potentially reveal more pronounced cross-cultural differences; (2) validate the findings of this study using high-fidelity driving simulators or controlled on-road test environments under simulated or real driving conditions.

6. Conclusion

This study systematically investigated the effects of icon semantic distance and cultural background on visual search efficiency for functional icons in vehicle control interfaces through two experiments. The findings indicate that semantic distance significantly affected both visual recognition efficiency (comprising recognition time and accuracy) and visual search time, with icons of closer semantic distance demonstrating overall superior performance across these metrics. Additionally, cultural background also exerted a significant influence on visual search efficiency (comprising search time and accuracy) as well as visual recognition time. Notably, a significant interaction was observed between semantic distance and cultural background for search time, wherein variations in semantic distance had a more pronounced impact on South Asian users. It should be noted that this study carries certain limitations regarding sample composition and scenario simulation. Their applicability to expanded samples and to time-pressured, high-cognitive-load driving scenarios merits further investigation. On the theoretical front, this study clarifies the proximity and remoteness attributes of semantic distance for each functional icon, as well as reveals their differences in cross-cultural semantic cognition. On the practical front, it not only provides a reusable evaluation methodology for the global interface design of Chinese automotive brands, but also offers specific and actionable icon design references for enhancing visual search efficiency among users from different cultural backgrounds.

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CRediT Author Contributions Statement

Yunguo Liu: Conceptualisation, Methodology, Investigation, Resources. Zizhen Liu: Formal analysis, Writing-original draft, Writing-review & editing, Methodology, Visualization. Xuelin Tang: Writing-review & editing, Project administration, Supervision, Resources. Rang Meng:

Methodology, Data collation.

Data Availability

The datasets generated during and analysed during the current study are available from the corresponding author on reasonable request.

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Informed Consent

All participants were fully informed of the study's purpose, content, and methodology and provided their informed consent through the signing of consent forms, explicitly indicating their voluntary participation and agreement to the use of their data for the purposes of this study.

Competing interests

The authors declare no competing interests.

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