IPRPD
International Journal of Arts, Humanities and Social Sciences
ISSN 2693-2547 (Print), 2693-2555 (Online)
Volume 07; Issue no 09: September 2026
DOI: 10.56734/ijahss.v7n9a3

RESEARCH PROGRESS AND PROSPECTS OF COGNITIVE LOAD THEORY IN AGING-RESPONSIVE DESIGN OF AUTOMOTIVE INTERACTION INTERFACES

CHEN Ge[1], WANG Haojie[2]

[12]*Zhengzhou University of Light Industry*

Abstract

Objective As the functions of automotive human–computer interaction interfaces multiply, system complexity deepens. This study focuses on the driving safety and experience of older drivers. It examines recent progress in applying cognitive load theory to the aging-responsive design of automotive interaction interfaces, and systematically reviews the research methods and measurement approaches of cognitive load theory.

Methods Through literature review and induction, this study summarizes the research methods and applications of cognitive load theory. Using CiteSpace, keyword co-occurrence and burst analyses were performed on literature from the past 15 years retrieved from CNKI and WOS to identify research foci and emerging trends.

Conclusion Currently, automotive interaction interfaces give insufficient attention to older users, and research applying cognitive load theory in this field remains shallow. Systematic studies of intrinsic, extraneous, and germane cognitive load in the presentation and control of driving-interface information therefore hold considerable research value.

Keywords

Cognitive Load; Automotive Interaction Interface; Aging-Responsive Design; Older Adults

Cognitive load is a theory proposed by John Sweller et al. in the 1980s, which aims to improve the efficiency of learning activities by presenting information in a manner that optimizes intellectual performance. Sweller classified cognitive load into intrinsic cognitive load, extraneous cognitive load, and germane cognitive load; the three types of cognitive load superimpose on one another, constituting the total amount of mental cognitive resources used by humans during information processing.[1] At present, cognitive load theory has gradually developed toward integration with the field of human–computer interaction, and reducing intrinsic and extraneous cognitive load while increasing germane cognitive load has become the research focus of cognitive load theory in digital interface interaction design.

1 Visualized Analysis of Cognitive Load Theory Based on CiteSpace

1.1 Literature Sources

After searching related academic journals on CNKI, it was found that a subject search for “Research on Aging-Responsive Design of Automotive Interaction Interfaces Based on Cognitive Load Theory” returned zero results; the subject search terms were therefore changed to “cognitive load in older adults”, “cognitive load in human–computer interaction”, and “aging-responsive automotive interaction interfaces”. The literature on cognitive load in older adults mainly concerns improving older adults’ experience of using smart products by reducing cognitive load, as well as the influence of cognitive load on older adults’ behavior and emotional memory; research reviews of cognitive load in human–computer interaction have been published, with the largest number of studies in the

[1] Funding:General Project of Humanities and Social Science Research of Henan Provincial Colleges and Universities (2022-ZZJH-117); Henan Philosophy and Social Science Research Youth Project (2022CYS058, 2023CYS056)

direction of digital interface design; the search results for "aging-responsive automotive interaction interfaces" are scarce, with only two relevant publications. The CNKI search results of the related literature are shown in Table 1-1.

Table 1-1 List of CNKI Search Results of the Related Literature

Search term	Journal articles			Theses	
	Total journal articles	Core journal articles	Journal articles in the recent 5 years	Total theses	Theses in the recent 5 years
Cognitive load in older adults	15	11	14	33	19
Cognitive load in human–computer interaction	21	11	11	15	13
Aging-responsive automotive interaction interfaces	Qiu Dapeng (2020), "Research on Aging-Responsive Design of Automotive Human–Computer Interaction Based on the Driving Behavior of Older Adults" Lin Yuting (2020), "Research on Aging-Responsive Design of Automotive Central-Control Human–Machine Interfaces Based on the FBM Model" Mi Liangyu (2023), "Research on Aging-Responsive Design Strategies for Automotive Human–Computer Interaction Interfaces Based on Cognitive Load Theory"				

The Chinese journal data were obtained from the China National Knowledge Infrastructure (CNKI) journal database. The search criterion was the subject term "cognitive load", and the journal source categories were limited to Peking University Core journals, CSSCI, EI, and SCI. The publication period was limited to January 1, 2008–May 1, 2023, and 759 relevant articles were retrieved in total. For foreign literature, the WOS Core Collection was selected with the subject term "Cognitive load" under the same time limit, and 8,957 relevant articles were selected in total.

1.2 Publication Volume and Trends of the Literature

Fig. 1 shows the annual publication volumes of domestic and foreign journals from 2010 to 2022. Through visualized analysis, the publication volumes of both Chinese and foreign journals exhibit an increasing trend, but the number of articles published in foreign journals is higher than that in Chinese journals, and the growth trend abroad is also steeper. As early as the 1980s, the Australian cognitive psychologist John Sweller[2] took cognitive load (Cognitive Load, CL) as a theory for experimental research, and proposed the limited-resource theory and schema theory as the theoretical foundations of cognitive load, after which foreign scholars began to explore the field of cognitive load. In China, research on cognitive load first appeared in Xu Yuanli's (1997) "Shortcomings of Traditional Teaching Methods from the Perspective of Cognitive Load", and some early studies mainly focused on curriculum teaching and instructional design.

Fig. 1 Annual distribution of the publication volume of domestic and foreign literature on cognitive load theory research, 2010–2022 (self-drawn)

1.3 Analysis of Research Hotspots and Evolution

1.3.1 Keyword Co-occurrence Analysis

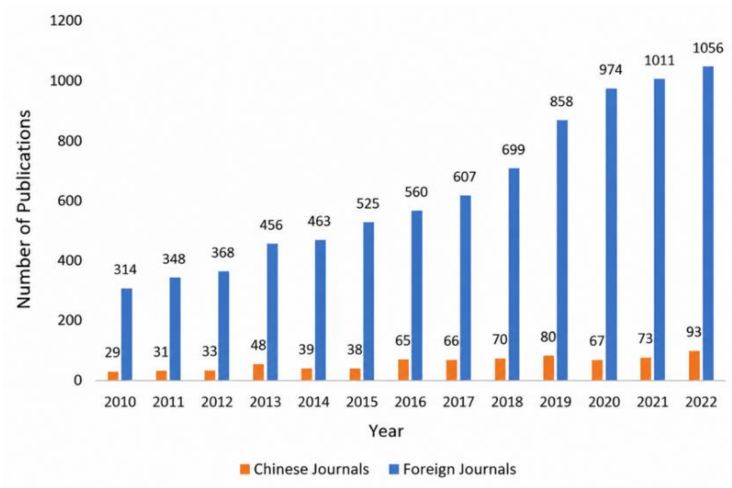

Fig. 2 is a keyword clustering map generated with CiteSpace software based on Chinese journals in CNKI, which combines keywords with similar concepts into conceptually independent clusters. The Q value of clustering is 0.6936 and the S value is 0.9482, indicating that the clustering structure is significant and convincing. The map yielded 10 cluster labels, among which the keywords “cognitive load” and “cognitive load theory” are duplicative, so 9 labels remain effective. Ranked by cluster labels, the top five main domains are cognitive load, learning effect, eye tracking, human–computer interaction, and intrinsic cognitive load. The map reveals the close connection of cognitive load with working memory and learning effect, as well as the application of eye-tracking technology in cognitive load research; meanwhile, research on cognitive load has also deepened into the three types of intrinsic cognitive load, extraneous cognitive load, and germane cognitive load.

The rapid development of the Internet has greatly increased the density of information acquired by humans, and how to improve cognitive efficiency has attracted attention. With the deepening of cognitive load research, cognitive load theory has gradually penetrated into other fields such as human–computer interaction and virtual reality, which represents a new exploration in the design field. Fig. 3 is the CiteSpace keyword co-occurrence map based on foreign journals from WOS. The main keywords are “cognitive load”, “working memory”, “instructional design”, “mental load”, “attention”, and “individual differences”. Compared with the distribution of the main keywords in Fig. 2, it can be found that foreign journals focus more on basic theoretical research on cognitive load, whereas Chinese journals focus more on its applications. On the other hand, the keyword that appears with high frequency in both Chinese and foreign literature is working memory. John Sweller’s limited-resource theory holds that cognitive load arises when the demand for cognitive resources exceeds the total amount of cognitive resources a person possesses, that is, human working memory capacity is limited, and excessive information causes insufficient attentional resources[3].

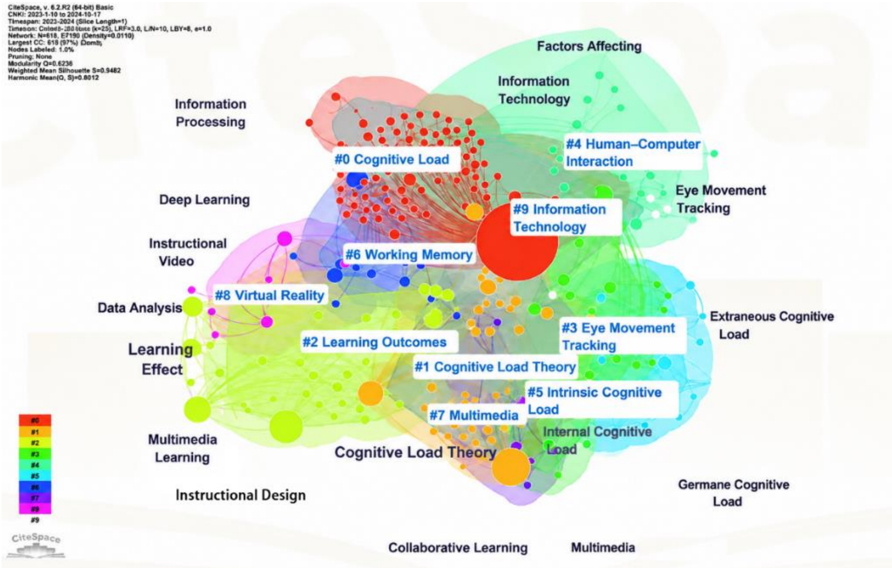

Fig. 2 Keyword clustering map of cognitive load theory research based on CNKI, 2010–2023 (self-drawn)

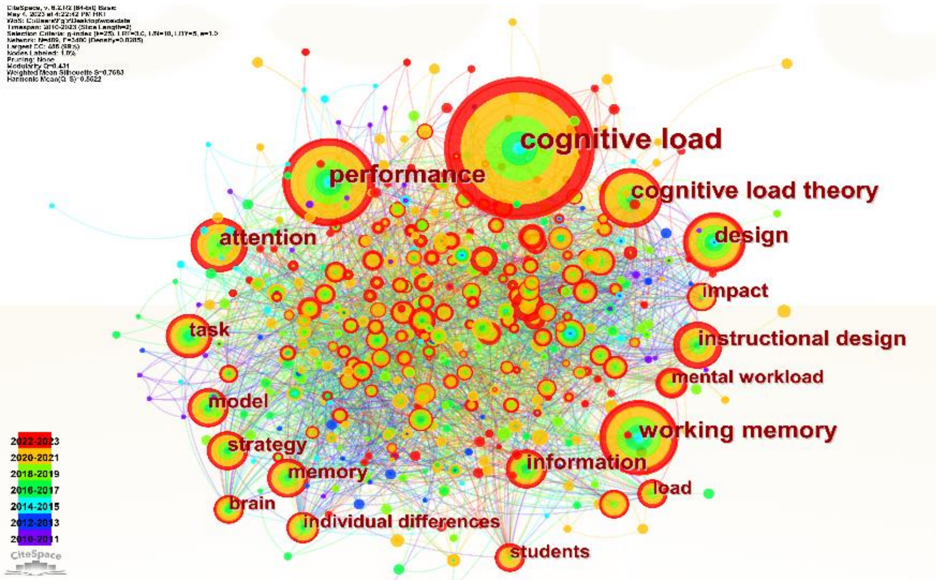

Fig. 3 Keyword co-occurrence map of cognitive load theory research based on WOS, 2010–2023 (self-drawn)

1.3.2 Analysis of Research Trends

The Burst Detection function in CiteSpace was used to generate burst keywords, enabling the evolutionary trends of research hotspots to be explored from a temporal perspective. Fig. 4 shows the burst keywords of cognitive load theory based on CNKI, from which the 20 keywords with the highest burst frequencies were screened out. According to different time periods, research on cognitive load theory can be divided into three stages.

1) 2010–2015 was the accumulation stage of the research. Six burst keywords appeared in total, with an average burst strength of 2.59; representative keywords include “working memory”, “cognitive load theory”, “information processing”, and “information technology”. The research focus of this stage was the study of cognitive load theory in information processing, providing new frontiers and theoretical support for subsequent research and applications.

2) From 2016, new burst keywords emerged; seven burst keywords appeared in total in this stage, with an average burst strength of 2.29. Representative keywords include “flipped classroom”, “teaching model”, “extraneous cognitive load”, and “deep learning”, indicating that the research applications of cognitive load theory focused on teaching and learning. Zhao Donghua[Error! Reference source not found.] discussed the implications and development strategies of cognitive load theory for the design of flipped classrooms, and put forward suggestions on how to reduce learners’ cognitive load and improve learning efficiency. Research on cognitive load theory in the teaching field remains an important research hotspot to this day and has potential research significance in the context of Internet-based distance education and the era of artificial intelligence.

3) After 2018, the number of burst keywords was seven, with an average burst strength of 2.82; representative keywords include “eye tracking”, “instructional video”, “eye-movement experiment”, “learning effect”, “meta-analysis”, and “virtual reality”. This stage introduced a new research tool, eye-tracking technology: by analyzing indicators such as saccades, fixations, and blinks, the psychological load of participants can be reflected. For example, Xue Yaofeng[5] et al. analyzed three eye-tracking indicators—fixation duration, number of fixations, and pupil diameter—and constructed a quantitative model of cognitive load in online learning based on eye-tracking technology. On the other hand, attention to the empowerment of augmented reality and virtual reality technologies, especially their role in reducing users’ cognitive load, became a research hotspot. For example, Wang Guohua[Error! Reference source not found.] adopted a meta-analysis to explore the moderating effects of variables such as subject, learning stage, and intervention duration on the influence of virtual reality on cognitive load, and concluded that virtual reality technology as a whole plays a moderate facilitating role in reducing cognitive load.

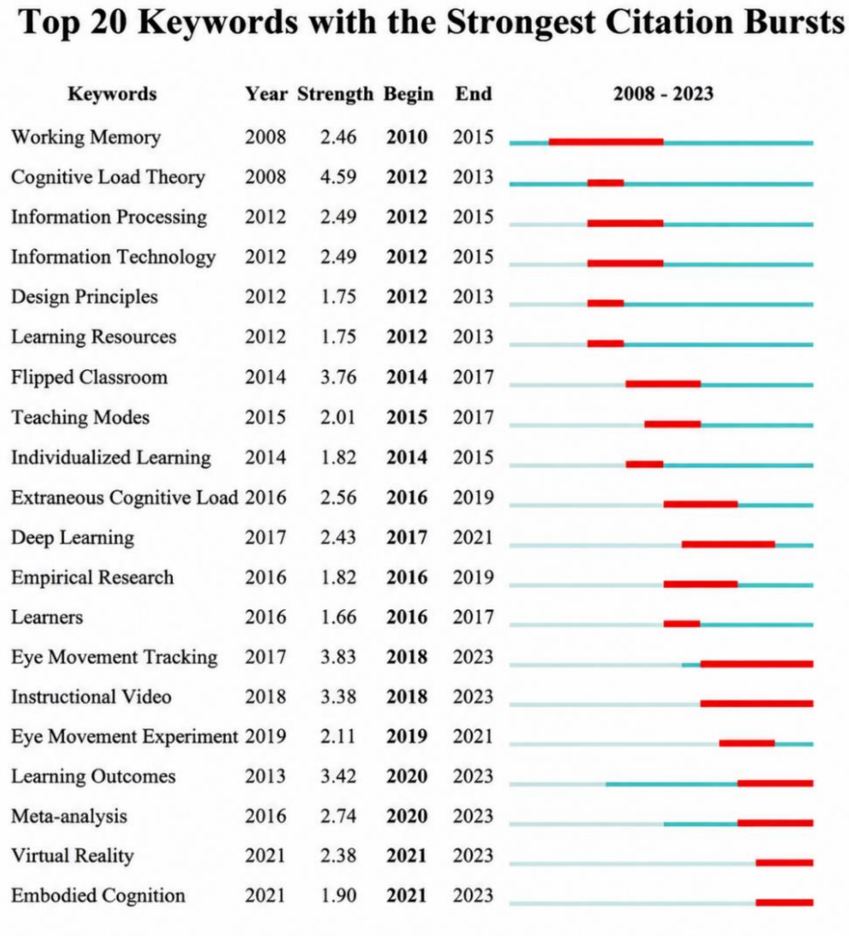

Fig. 4 Burst keywords of cognitive load theory based on CNKI

As can be seen from the keyword co-occurrence map and the burst-word map, research on cognitive load theory is mainly dispersed across multiple application fields such as education, human–computer interaction, and virtual reality. In the future, reducing the cognitive load of learners or users in activities and improving work and learning efficiency will remain the main concerns; exchanges and cooperation among different disciplines should be strengthened, and more research tools and measurement methods should be introduced to enrich research on cognitive load theory.

2 Research Status of Cognitive Load Theory in Aging-Responsive Design of Automotive Interaction Interfaces

2.1 Research Status of Cognitive Load Measurement Methods

In "Research Status and Development Trends of Cognitive Load in Human–Computer Interaction", He Xiaomei (2023) systematically analyzed cognitive-load-based human–computer interaction research from three dimensions: the types of cognitive load in human–computer interaction, measurement methods, and related research variables, elaborating on each dimension in detail, and also analyzed and summarized the applied research on cognitive load in human–computer interaction. Currently, research on cognitive load in human–computer interaction mainly focuses on extraneous cognitive load, and the measurement methods used mainly include objective measurement methods (such as eye tracking and cognitive activity index) and subjective measurement methods (such as the Paas mental effort scale and the NASA-TLX scale); at present, cognitive load research in the course of user experience receives relatively little attention, and there is also little research on the different cognitive load conditions exhibited by individuals with different cognitive abilities on the same human–computer interaction interface[7]. In particular, the cognitive load of older adults is rarely considered in digital interfaces. Research on the aging-responsive design of automotive interaction interfaces can take attention to older adults' cognitive load and the reduction of cognitive load levels as its entry point, and the selection of appropriate cognitive load measurement methods is also of great importance.

2.2 Research Status of Cognitive Load in Older Adults

CNKI-based research on cognitive load in older adults has gradually increased over the past five years, reflecting the deepening population aging in China and society's growing attention to older adults, although the total number of articles is not large. The main research field lies in the interaction interfaces of smart products. Wang Haibo[8] studied older adults' use of the interaction interface of a smart rice cooker based on cognitive load, and improved the rice cooker through theories such as natural interaction and distributed cognition, reducing intrinsic and extraneous cognitive load and indirectly increasing germane cognitive load, thus improving the user experience of older adults. Shan Runhou[9], in a visual ergonomics study on differences in the hue of interface backgrounds, proposed that when lightness and saturation remain unchanged, the hue difference and hue complexity of the background significantly affect the cognitive load of middle-aged and older adults.

Web of Science-based research on cognitive load in older adults is mostly conducted from medical and psychological perspectives, and human–computer interaction interface research mainly concerns online learning. Huang, TY[Error! Reference source not found.] investigated the cognitive load of older users' interface experience during online learning, combining objective eye-tracking technology with the subjective Paas scale to measure cognitive load, thereby improving their user experience. Shi, Aiqin[11] experimentally compared linear hierarchical navigation and hybrid hierarchical navigation, and found that the linear hierarchical navigation structure performs better in usability in terms of task efficiency, cognitive load, and subjective ratings, making it more suitable for older adults to learn on smartphones.

In addition, there is little research on the cognitive load that older adults experience with automotive interaction interfaces during driving. At present, research on automotive interaction interfaces based on cognitive load already exists: in "Research on the Design of In-Vehicle HUD Interaction Interfaces Based on Cognitive Load", Wang Yingjie (2021) proposed evaluation indicators for the cognitive load of in-vehicle HUD interaction interfaces, selecting objective indicators such as driving reaction time and reading accuracy combined with subjective scales to jointly form the evaluation system; research and practice have proved that the in-vehicle HUD interaction interface design strategy based on cognitive load can improve the usability of existing interfaces. However, that study did not segment the user population and overlooked individual differences among older adults. Future research can therefore extend this work by examining how cognitive load levels differ across populations, especially among older adults.

2.3 Research Status of Aging-Responsive Design of Automotive Human–Computer Interaction Interfaces

At present, there is much research both at home and abroad on automotive human–computer interaction design; corresponding design strategies and design principles have been summarized, and the design of interaction modes through different channels has been explored[12]. The latest research in CNKI mainly concerns human–computer interaction design in automated driving scenarios, virtual simulation for developing driving simulators, and multimodal interaction design. For example, Sun Xiaofeng et al. [13] designed a human–computer interaction trust model for automated vehicles and found through research that the information channel, system transparency, and information carrier significantly affect trust in automated driving. Guo Hongyan et al.[14] proposed a scenario generation method that comprehensively considers the frequency with which scenarios occur in the real world and the degree to which they challenge vehicle–human interaction performance. The latest literature in Web of Science mainly concerns the design of intelligent automotive interaction interfaces. For example, Xia, TS et al.[15] constructed a model of users' intention to use automotive AR-HUD based on the theory of reasoned action and the unified theory of technology acceptance and use; questionnaire results showed that users' effort expectancy influenced their intention to use the AR-HUD through the mediating role of performance expectancy. Gruden, Timotej et al.[Error! Reference source not found.] investigated the key points of HMI design for vehicle take-over requests that notify drivers to take back vehicle control; based on user evaluation of directional tactile and auditory user interfaces, they found that drivers' attention is redirected more quickly under the auditory UI.

In research on the aging-responsive design of automotive human–computer interaction, there are few publications concerning older adults' use of automobiles. Among Chinese-language studies, Li Yongfeng et al.[17], based on failure mode and effects analysis (FMEA) and fault tree analysis (FTA), took automotive interfaces for older adults as an example; this method can effectively identify the causes of errors made by older adults when operating automotive interfaces. Liu Zhiwei et al.[18] studied the acceptance of automated vehicles by older adults in the context of the digital divide and found that for older adults as a whole, perceived behavioral control is the most important factor affecting their acceptance of automated vehicles; for the group of older adults with weak digital capabilities, subjective norms are the most important factor; and for the group of older adults with strong digital capabilities, attitude is the most important factor. Among English-language studies, Ryu, Jae-Heok et al.[19], by considering the physical and cognitive characteristics of older adults, put forward some design suggestions for automotive interior design regarding cluster colors and fonts, display positions, and HVAC controls. Jung, SB et al.[Error! Reference source not found.] investigated the rising rate of fatal accidents among older drivers worldwide, and proposed a design concept for a usable vehicle system that adopts facial-expression recognition technology as a solution, aiming to reduce the growing number of fatal accidents among older adults by considering their usability and physical conditions.

3 Analysis of the Current Research Status

Taken together, the above research status shows that, against the backdrop of population aging in China, research on older adults has gradually gained attention in the automotive driving field. Research on older adults' physical conditions and perceptual abilities started earlier abroad, where cognitive load theory has been widely used to study older adults. Combining these foreign theoretical methods with the actual conditions of domestic society can help improve the driving experience and safety of older adults.

1. Using CiteSpace software to analyze papers selected from CNKI and WOS with the subject term "cognitive load", it was found that there is a close connection between cognitive load and working memory as well as learning effect, that eye-tracking technology has been widely applied in cognitive load research, and that research on cognitive load has also deepened into the three types of intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. In addition, the application scope of cognitive load theory has gradually expanded from the early fields of curriculum learning and instructional design to fields such as human–computer interaction and virtual reality.

2. By searching the subject terms "human–computer interaction" and "cognitive load", it was found that the current research and measurement methods for cognitive load in human–computer interaction mainly combine objective measurement methods (such as eye tracking and cognitive activity index) with subjective measurement methods (such as the Paas mental effort scale and the NASA-TLX scale).

3. There is little research based on cognitive load theory on older adults' use of automotive interaction interfaces; in automotive human–computer interaction such as in-vehicle HUD and AR-HUD, the differences of the older population have been ignored. Future research can continue to explore this direction by combining the related research foundations on older adults' use of the interaction interfaces of other smart products, such as the influence of differences in interface background hue or interface information navigation structure on the user experience of older adults. On the other hand, in the field of human–computer interaction, existing research has concentrated on reducing intrinsic and extraneous cognitive load, while germane cognitive load has received less attention; germane cognitive load can be leveraged to promote learning and optimize task performance.

4 Conclusion and Prospects

Through literature analysis, this study employed CiteSpace software to conduct publication-volume trend analysis, keyword co-occurrence analysis, and burst-word analysis. Combining the constructed knowledge maps and statistical tables, it analyzed the research hotspots and trends of cognitive load theory both at home and abroad, and further elaborated on research concerning the application of cognitive load theory to the aging-responsive design of automotive interaction interfaces from three aspects: measurement methods, attention to the older population, and automotive interaction interfaces.

At present, research on cognitive load theory in the aging-responsive design of automotive interaction interfaces has already attracted researchers' attention. Beyond the research perspectives discussed above, such as exploring cognitive load measurement methods and reducing intrinsic and extraneous cognitive load, in-depth research can proceed from intrinsic cognitive load, extraneous cognitive load, and germane cognitive load to study the quality and presentation of interface information, taking into account the differences between older adults and younger people in the cognitive processing of information, so as to improve design and evaluation methods. Among these, germane cognitive load refers to schema construction and automation with respect to information; from the perspective of interface design, strengthening the schema availability of information helps promote the matching degree and relevance of drivers' cognitive memory, thereby enhancing the user experience of automotive interaction interfaces.

References

Sweller, J. (2011). Cognitive load theory. *Psychology of Learning and Motivation*, *55*, 37–76.

Xu, Y., Li, Y., & Zhu, X. (1998). A new method for evaluating problem difficulty: A cognitive load measurement model. *Advances in Psychological Science*, *6*(2), 6–10.

Gong, D. (2009). *Optimization management of cognitive load in multimedia learning* [Doctoral dissertation, Southwest University].

Zhao, D. (2016). On cognitive load theory and its implications for flipped classroom design. *China Adult Education*, *(19)*, 94–96.

Xue, Y., & Li, Z. (2019). Research on a quantitative model of cognitive load in online learning based on eye-tracking technology. *Modern Educational Technology*, *29*(7), 59–65.

Wang, G., Song, J., Tian, L., Zhang, Y., & Chen, X. (2023). Does virtual reality technology help reduce learners' cognitive load? A meta-analysis based on 23 experimental and quasi-experimental studies. *Open Education Research*, *29*(4), 110–120.

He, X., He, S., & Shao, J. (2023). Research status and development trends of cognitive load in human–computer interaction. *Computer Integrated Manufacturing Systems*, *29*(4), 1069–1081.

Wang, H., Hu, R., Guo, H., & Zhang, T. (2018). Research on the interaction prototype of a smart rice cooker for older adults based on cognitive load. *Packaging Engineering*, *39*(22), 213–217.

Shan, R., & Sun, Q. (2022). Visual ergonomics of background hue differences in interfaces for middle-aged and older adults based on cognitive load. *Popular Science & Technology*, *24*(7), 196–200.

Huang, T., & Zhang, J. (2022). Study on experience design of elderly online learning interface based on cognitive load. In M. Kurosu (Ed.), *Human–Computer Interaction: User Experience and Behavior* (HCII 2022). *Lecture Notes in Computer Science*, *13304*. Springer.

Shi, A., Huo, F., & Han, D. (2021). Role of interface design: A comparison of different online learning system designs. *Frontiers in Psychology*, *12*, 681756.

Qiu, D. (2020). *Research on aging-responsive design of automotive human–computer interaction based on older drivers' driving behavior* [Doctoral dissertation, Jiangnan University].

Sun, X., Zhao, Y., & Lyu, C. (2022). Influence mechanism of human–computer interaction trust in automated vehicles. *Journal of Northeastern University (Natural Science)*, *43*(9), 1305–1313.

Guo, H., Zhang, J., Liu, J., & Hu, Y. (2024). Construction of virtual test scenario for intelligent vehicle and pedestrian interaction. *Journal of Jilin University (Engineering and Technology Edition)*, *54*(9), 2511–2519.

Xia, T., Lin, X., Sun, Y., & Liu, T. (2023). An empirical study of the factors influencing users' intention to use automotive AR-HUD. *Sustainability*, *15*(6), 5028.

Gruden, T., Tomažič, S., Sodnik, J., & Jakus, G. (2022). A user study of directional tactile and auditory user interfaces for take-over requests in conditionally automated vehicles. *Accident Analysis & Prevention*, *174*, 106766.

Li, Y., & Chen, Z. (2021). Research on the interaction design of automotive human–machine interfaces for older adults based on FMEA and FTA. *Packaging Engineering*, *42*(6), 98–105.

Liu, Z., & Liu, J. (2023). Older adults' acceptance of automated vehicles in the context of the digital divide. *Journal of Transportation Systems Engineering and Information Technology*, *23*(2), 168–175.

Ryu, J., Park, Y., & Kim, H. (2009). Improving in-vehicle display and control design for older drivers. In B. T. Karsh (Ed.), *Ergonomics and Health Aspects of Work with Computers* (EHAWC 2009). *Lecture Notes in Computer Science*, *5624*. Springer.

Jung, S., Meng, H. Y., & Qin, S. F. (2017). Exploring challenges in developing a smart and effective assistive system for improving the experience of the elderly drivers. *Chinese Journal of Mechanical Engineering*, *30*, 1133–1149.