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EXPLORATORY CHARACTERISTICS OF SENSORY COMPENSATION FOR VISUALLY IMPAIRED PEOPLE

Xiao Ranting[1], Azhari Md Hashim[2*], Han Jianwu[3], and Pibool Waijittragum[4]

[1,2,3] Faculty of Art & Design, Universiti Teknologi MARA (UiTM), Kedah Branch Campus, Malaysia
Email: 1159437227@qq.com[1], azhari033@uitm.edu.my[2], 2500780258@qq.com[3]
[1,3] Jiangxi Institute of Fashion Technology, Nanchang City, Jiangxi Province, Republic of China
Email: 1159437227@qq.com[1], 2500780258@qq.com[3]
[4] Faculty of Fine and Applied Arts, Suan Sunandha Rajabhat University, Thailand
Email: pibool.wa@ssru.ac.th
[*] Corresponding Author

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Abstract:

The visually impaired population continues to grow at a steady rate each year. However, a review of current products developed for this population reveals significant shortcomings, including limited product variety, single-function designs, and a lack of innovation. This study aims to gain a deeper understanding of the sensory compensation mechanisms employed by visually impaired individuals. By systematically exploring the application of sensory compensation mechanisms in product design, this research seeks to overcome the limitations of existing assistive devices, which often only meet functional requirements and fail to align with the sensory information pathways of visually impaired users. The ultimate goal is to develop designs that optimise information transmission pathways, thereby reducing cognitive load during product use. This study employs literature review and market research methods to examine the characteristics of visually impaired individuals and the categories, cases, and shortcomings of existing assistive products for the visually impaired. It summarises the primary characteristics of visually impaired individuals and the perception methods of existing assistive products, conducts an in-depth analysis of the effectiveness and application of sensory compensation pathways, and provides insights for future empirical research and product design targeting visually impaired individuals.

Keywords:

Sensory Compensation; Visually Impaired; Perception Pathways; Visually Impaired Products

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Introduction

According to the World Health Organisation (WHO) (2010) Global Status Report on Vision, there are approximately 36 million people worldwide who are blind, 217 million people with moderate or severe visual impairments, 188 million people with mild visual impairments, and 109 million people aged 35 and above who are affected by visual impairments due to functional presbyopia. Based on population statistics from countries around the world, China has the largest population of visually impaired individuals and the highest proportion of visually impaired individuals relative to the total population (as shown in Figure 1). According to data from the 2021 China Disability Statistics Yearbook, as of the end of 2020, the total number of registered disabled persons in China had exceeded 37.8 million. Among them, the scale of the visually impaired population reached 4.2 million, accounting for 11.11% of the total disabled population, highlighting the significant role of the visually impaired population among special needs groups (Wang Qi et al., 2022).

WHO REGION	Total population (million people%)	Total Blindness (% per million people)	Low vision (% per million people)	Total number of visually impaired individuals (% per million people)
Africa	804.9 (11.9)	5.888(15)	20.407 (8.3)	26.295 (9.2)
Americas	915.4 (13.6)	3.211 (8)	23.401 (9.5)	26.612 (9.3)
Eastern Mediterranean region	580.2 (8.6)	4.918 (12.5)	18.581(7.6)	23.499 (8.2)
Europe	889.2 (13.2)	2.713 (7)	25.502(10.4)	28.215 (9.9)
Southeast Asia (excluding India)	579.1 (8.6)	3.974 (10.1)	23.938 (9.7)	27.913 (9.8)
West Coast of the Pacific (excluding China)	442.3 (6.6)	2.338 (6)	12.386 (5)	14.724 (5.2)
India	1181.4 (17.5)	8.075 (20.5)	54.544 (22.2)	62.619 (21.9)
China	1344.9 (20)	8.248 (20.9)	67.264 (27.3)	75.512 (26.5)
TOTAL	6737.5 (100)	39.365 (100)	246.024 (100)	285.389 (100)

Figure1 ：World Health Organisation 2010 Survey on Visual Impairment in the Global Population

Source: World Health Organisation

Facing such a large visually impaired population, the market for assistive products for visually impaired individuals both domestically and internationally currently faces a significant imbalance between supply and demand, with limited product types, restricted functionality, and insufficient quantities (Gu Sumei et al., 2023). This results in visually impaired individuals still encountering numerous obstacles in daily use, making it difficult to truly achieve a "user-centred" design philosophy (Xiong Xingfu et al., 2009). Against this backdrop, the introduction of sensory compensation design principles has provided a new approach to addressing this issue and has played a significant role in advancing research in the field of assistive products for the visually impaired.

In-depth research on sensory compensation products has revealed that as products become more multifunctional and intelligent, their rapid updates and iterations leave special populations feeling overwhelmed by their use and operation. Against this backdrop, as pain points continue to emerge, it has prompted us to rethink product design for vulnerable groups, approaching the issue from the perspective of sensory compensation, analysing the application scope, advantages, and disadvantages of existing products, and identifying opportunities for integration (Yang Jing, 2018).

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Literature Review

Overview of Sensory Compensation

According to Han Feifei (2021), the development of sensory compensation theory has undergone a cross-disciplinary evolution from biology to design science. Initially, this phenomenon was discovered and studied in the field of biological evolution. Research conducted by Professor Zhang Shuyi's team at East China Normal University in collaboration with scholars from the United Kingdom and Ireland on bats revealed that although bats have weak visual senses, they have developed a highly sensitive auditory echolocation system, enabling them to accurately determine the location of prey. This demonstrates that sensory compensation serves as an important adaptive mechanism.

When applied to human research, this refers to the phenomenon where, when a certain sensory organ in the human body is damaged or loses its function, other sensory organs actively or passively enhance their own functions to compensate for the lost sensory abilities, thereby maintaining the normal functioning of the body. In simple terms, when a sensory function is impaired, other senses enhance their perceptual capabilities to form a compensatory effect. Additionally, this compensatory mechanism follows certain balance principles: when one sensory ability significantly enhances, other sensory functions may correspondingly weaken. This phenomenon stems from the brain's cross-modal plasticity, which allows the brain to reallocate neural pathways and redistribute resources from brain regions originally responsible for the impaired sense to other senses.

The principle of sensory compensation was first applied in product design in the 1960s to assist visually impaired individuals in locating and identifying objects through audiovisual or visual-tactile conversion systems (AUVRAY M et al., 2009). In industrial design, this concept has been transformed into an active design strategy that enhances the interactive experience of products across multiple sensory dimensions, such as tactile and auditory, to compensate for sensory impairments in specific user groups.

According to sensory compensation theory and scientific research, if a sensory organ is damaged, other sensory organs in the human body will automatically enhance or provide varying degrees of compensation to restore the ability to perceive objects. The human sensory system includes hearing, vision, smell, touch, and taste. Due to visual impairments, visually impaired individuals cannot obtain basic information about objects, their location, or their shape through vision. However, under the guidance of sensory compensation design theory, they can rely on other senses to obtain information, process their prior knowledge, formed memories, and imagination, and transform them into their own cognitive understanding. The figure below illustrates the cognitive transformation process for visually impaired individuals based on sensory compensation theory (please refer to Figure 2).

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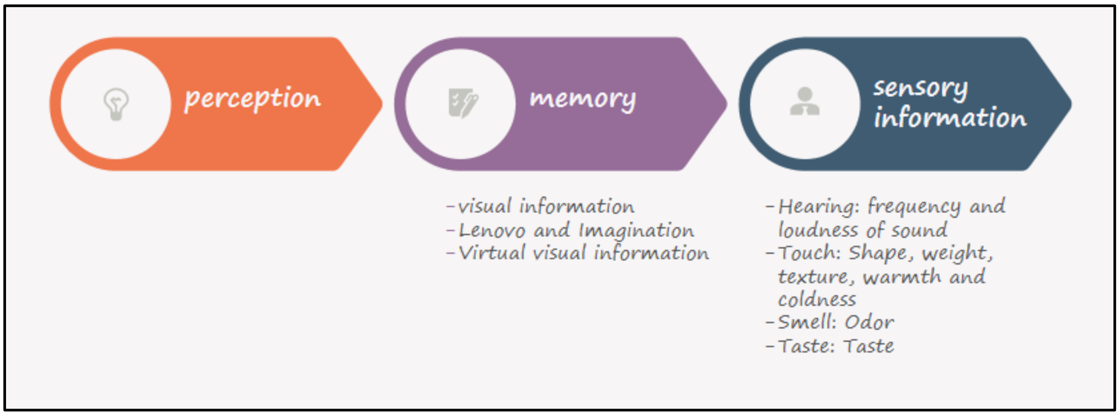

Figure 2: Cognitive Transformation Process of Visually Impaired Persons Based on The Theory of Sensory Compensation.
Source: Sensory Compensation theory

Characteristics Of Visually Impaired Individuals
The World Health Organization's classification standards for blindness and visual impairment provide a scientific basis for assessing visual impairments (see Table 1). China currently uses a two-tier classification system for visual impairments, dividing them into two main categories: blindness and low vision, with the first category being the most severe. Visual impairment grades are specifically classified as follows: Blindness (Grade 1, Grade 2): Grade 1 has best-corrected visual acuity <0.02 to no light perception, or a visual field radius <5°; Grade 2 has best-corrected visual acuity ≥0.02 but <0.05, or a visual field radius <10°, with clinical features indicating complete loss of light perception. Low vision (Grade 3 and Grade 4): Grade 3 has a best-corrected visual acuity of ≥0.05 but <0.1; Grade 4 has a best-corrected visual acuity of ≥0.1 but <0.3. Individuals in this category retain residual visual function but experience blurred vision and significantly impaired light perception. The low vision population includes individuals with refractive errors such as myopia, hyperopia, and astigmatism, whose visual perception is impaired but retains some object recognition ability. The lower the visual impairment grade, the more severe the disability, with Grade 1 being the highest disability grade. References mentioning visually impaired individuals or blind persons include classifications or definitions of visual impairments.

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Table1: Classification Criteria for Blindness and Visual Impairment

Visual impairment level	Long vision in daily life (double or good eyes)	
	Below	Better than or equal to
Level 0 (no visual damage)		0.5
Level 1 (mild visual impairment)	0.5	0.3
Level 2 (moderate visual impairment)	0.3	0.1
Level 3 (severe visual impairment)	0.1	0.05
Level 4 (blind)	0.05	0.02
Level 5 (blind)	0.02	light perception
Level 6 (blind)	No light perception	
Level 9	Uncertain or unspecified	

Source: Classification criteria for blindness and visual impairment developed by the World Health Organization

Visually impaired individuals exhibit complex emotional characteristics when facing their visual impairments, as they both hope for more care from others and place great importance on their privacy. In his research, Wu Xinlin (2020) found that 100% of visually impaired individuals hope to receive more attention from society. However, in 2002, China conducted a questionnaire survey on the social welfare status of people with disabilities. However, data analysis revealed that only 26.2% of the returned questionnaires were valid, with 64.7% being invalid. This phenomenon reflects the high importance that people with disabilities place on personal privacy and dignity. Additionally, visually impaired individuals exhibit curiosity and anticipation toward new things (Wang Qi et al., 2022).

The behaviour of visually impaired individuals is characterised by regularity and exploratory tendencies, with cognitive learning processes progressing from partial to holistic understanding. Wu Xinlin found through research that 84.9% of visually impaired households frequently organise items into categories to facilitate retrieval and reduce memory burden. Furthermore, researchers observed the behavioural habits of blind massage therapists at a massage parlor. Typically, when visually impaired individuals wish to perform a certain action, they first make a tentative movement using their hands, feet, or other body parts to perceive direction or object information, feeling their way forward to determine if the area is safe and free of hazards (Xiao Ranting et al., 2024). Only after confirming there is no danger do they take a step forward or begin the task. Even in familiar environments, this requires prolonged, consistent orientation training before they can confidently complete their activities. The cognitive process of visually impaired individuals is opposite to that of sighted individuals. They first touch a part of an object with their hands, gradually expanding the contact area to perceive the whole. The perception process involves sensory information being transmitted to the brain, where it is integrated to form a basic understanding of the local area, followed by a perception of the whole from the local area.

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Methodology

The literature review method used in this section is a mixed method with a qualitative focus and quantitative analysis as a supplement. Specifically, the qualitative analysis dimension involves analyzing the content of literature from China National Knowledge Infrastructure (CNKI), ProQuest, and Web of Science to deconstruct the theoretical framework of sensory compensation; the quantitative analysis dimension involves bibliometric statistics and time-series analysis of research trends (literature growth curves).

This section provides a detailed introduction to the data sources for the literature review. The researcher reviewed and integrated materials from three important databases in China and abroad. These three databases are CNKI, ProQuest, and Web of Science, covering multiple disciplines such as humanities and social sciences, natural sciences and engineering, medicine and health sciences, and emerging fields in both Chinese and English.

The selection of these three databases was primarily based on the following three considerations: First, the comprehensiveness of academic coverage. CNKI covers 98% of Chinese core journals and exclusively includes over 5,600 Chinese biomedical journals, making it suitable for accessing domestic research, particularly regarding assistive technologies, product design, and social support for visually impaired individuals; ProQuest aggregates global resources from 2,500 publishers, particularly in the humanities and social sciences, making it suitable for searching for sensory compensation theories and empirical research related to the visually impaired; Web of Science includes core collections such as SCIE/SSCI/A&HCI, covering over 12,000 high-impact journals across 254 disciplines. Second, methodological rigor is ensured to avoid data discrepancies. Data quality is also ensured, as all three databases require 100% peer review.

The inclusion criteria for articles are: (1) clearly addressing theories or applications related to sensory compensation; (2) the research subjects are visually impaired individuals (including blind or low-vision populations); (3) the focus is on assistive product design for visually impaired individuals. Search options include: visually impaired individuals, blind individuals, or low-vision populations, and sensory compensation. Articles are not restricted by country, region, or document type.

The search terms are (visually impaired individuals OR visually impaired groups OR blind individuals) AND (sensory compensation OR sensory compensation theory OR product design OR assistive tools) (subject). Refer to the figure 3 below, which is the flowchart of the literature review process for this section. The search was conducted using Boolean logic, yielding 133 initial documents on 15 July 2025. After screening and removing 67 documents that did not meet the criteria, 66 documents were ultimately included for analysis.

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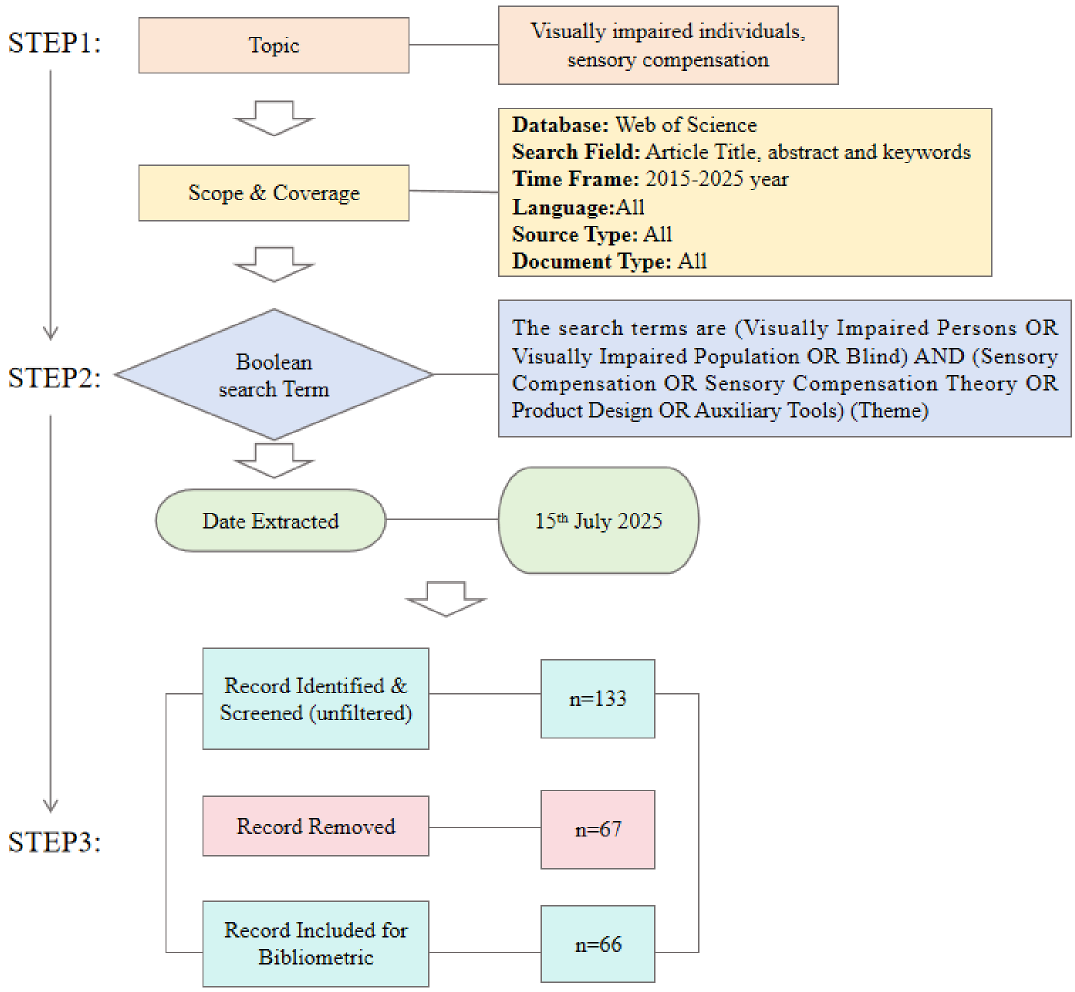

Figure 3: Flowchart

Source: Prepared by the researchers

China National Knowledge Infrastructure (CNKI) yielded 73 results, including journal articles and master's and doctoral theses, spanning the period from 2015 to 2025. After removing duplicates and articles with low relevance, 44 papers were retained. Web of Science yielded 29 relevant papers. When sorted by relevance, the results became less relevant on the second page. After removing irrelevant papers, 7 highly similar articles remained, all of which were journal articles. The ProQuest database contained 15 articles, including journal articles and master's and doctoral theses. The final sample included 66 articles (as shown in Table 2).

Table 2: References of Studies Included in this Paper

1	Cai Yizhe, Kuang Chunlin, Xi Zhijie, Li Chengcheng （2024）. Research on the design of fire escape masks for visually impaired individuals based on sensory compensation theory Art and Design (Theory), 2 (11), 29-31
2	Guo Xinyu (2024). Research on Product Design for Visually Impaired Children Based on Sensory Compensation Concept, Art Literature, 11,125-127
3	Li Wenqian, Guo Jiaxin, Zhong Xinchu, Yang Jin, Wang Chenke (2024). Modular toy design for visually impaired children based on tactile and auditory compensation Shanghai Packaging, 10,175-177

4	Sun Meiyin, Huang Xiyue (2024). Non visual imagery: Design and application of 3D relief voice photos for visually impaired individuals based on sensory compensation theory Ginseng, 21,50-52
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7	Zheng Zhiliang, Lian Yenuan (2023). Accessible Publishing: Sensory Compensation Interactive Experience Reading Construction Path China Publishing, 22,33-38
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10	Ren Yuyao, Lian Fei (2023). A review of research on inclusive urban spatial environment for people with sensory impairments New building, 03123-128
11	Zhang Yongnian, Zhao Yingjie, Fan Qingxi (2023). Research on multimodal interactive packaging design for visually impaired users Hunan Packaging, 38 (01), 159-163
12	He Xiaomei, Yang Ying (2023). A review of the current research status of accessible design methods Lake Packaging Project, 44 (06), 60-73+116
13	Liu Hexuan, Jack Ma (2022). Research on Product Demand Analysis for Visually Impaired Individuals in Home Environments Modern Marketing, 341160-162
14	Tang Xiangfei, Zhao Fengfeng (2020). Research on Sensory Compensation Design for Visually Impaired Population Based on Emotionalization Design, 33 (19), 10-12
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19	Jin Yimeng, Wu Shaolan (2016). Research on Interactive Medicine Box Design Based on the Needs of Visually Impaired People Design, 13126-127
20	Gu Sumei, Wang Xin, Li Yutong （2023）. Research on the Application of Sensory Compensation in Blind Product Design, Design, 36 (11), 76-79
21	Xia Haotian （2023）. Caring design based on sensory compensation for disabled individuals Jingdezhen Ceramic University
22	Liu Wenliang, Zhao Wanbing, Han Xue, Zhang Yongnian (2022). Research on the application of sensory compensation in the design of barrier free packaging for blind use of drugs Packaging Engineering. 43 (14), 213-220
23	Wang Qi, Guo Yan, Zhang Hongtao, Gu Sumei, Wang Xin (2022). Research on blind product design under sensory compensation Packaging Engineering. 43 (S1), 96-102
24	He Hua (2018). Exploration and research on barrier free product design for children with amblyopia Nanjing University of Science and Technology
25	Ren Yuyao (2023). Research on the Design of External Space Environment of University Campus Based on Sensory Compensation Harbin Institute of Technology
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Volume 7 Issue 22 (September 2025) PP. 576-595
DOI 10.35631/IJIREV.722032

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International Journal of Innovation and Industrial Revolution
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Source: China Knowledge Network (CNKI), ProQuest, and Web of Science Literature Statistics of Three Data Points

Research Results

This study analysed 66 papers published between 2015 and 2025 and found that the research trends showed distinct phase characteristics: early researchers mainly focused on basic research on the physiological and psychological characteristics of the target population, including tactile sensitivity and auditory localisation mechanisms; In the past five years, research has shifted toward the development of intelligent products, with a focus on three key areas: intelligent navigation devices (electronic canes integrated with ultrasound/GPS), daily assistive tools (smart pill boxes, readers, educational assistive tools, tableware, etc.), and multimodal interaction systems; simultaneously, the perception pathways of visually impaired individuals have evolved from single-modal to multi-sensory integrated approaches; The research perspective has expanded from functional needs to emotional design, with particular attention to the differentiated needs of different age groups, reflecting a complete knowledge evolution path from basic research to applied innovation.

Based on the above statistics, the first 44 papers are from China National Knowledge Infrastructure (CNKI), the next 45–51 are highly relevant papers from Web of Science, and the remaining 51–66 are papers published in the ProQuest database. Notably, the highest number of publications comes from CNKI in 2023 (as shown in Figure 4).

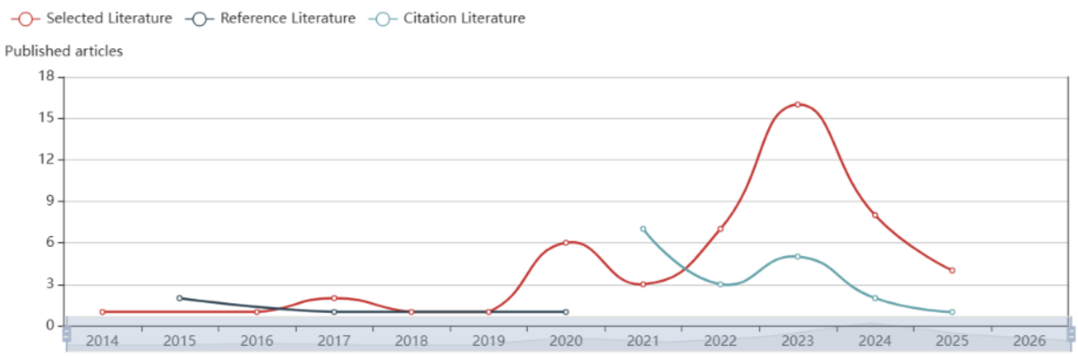

Figure 4: Table of The Number of Articles Published on China Knowledge Network (CNKI) In the Past Ten Years

Source: China National Knowledge Infrastructure (CNKI)

With the rapid development of information technology and the rapid iteration of smart products, the diversification and intelligence of product functions have been rapidly improving. Against this backdrop, the pain points of visually impaired people in the information society have become increasingly apparent, prompting people from all walks of life to rethink the needs of disadvantaged groups. According to the latest research data, between 2020 and 2023, the number of smart assistive products developed for the visually impaired has grown rapidly,

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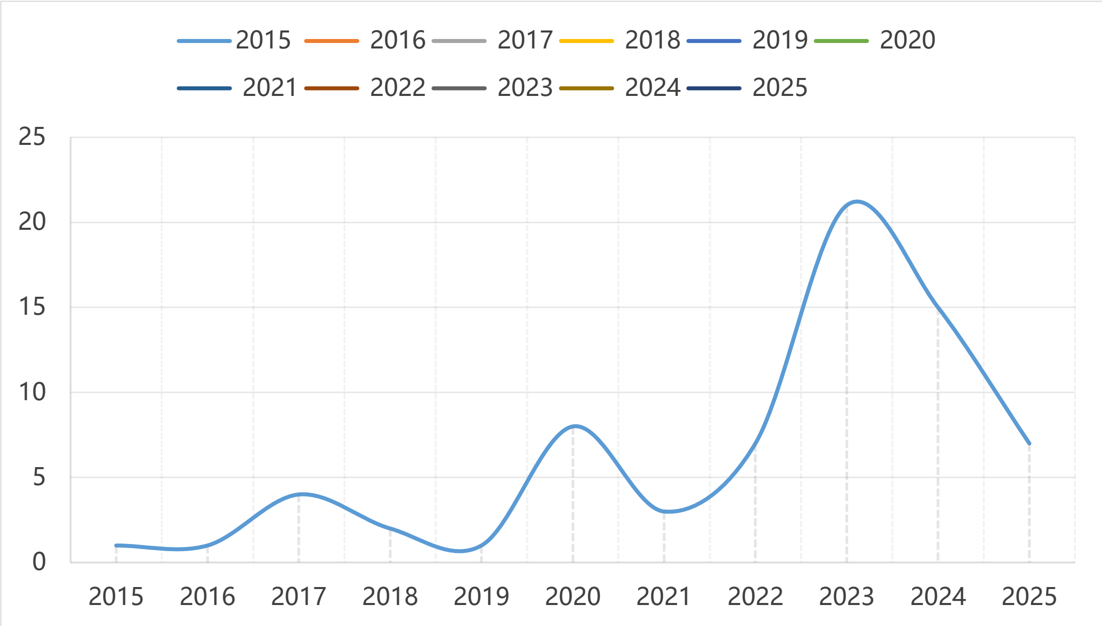
Volume 7 Issue 22 (September 2025) PP. 576-595
DOI 10.35631/IJIREV.722032
reflecting the deep integration of technological development and social care(as shown in Table 3).

Table 3: Number of Articles Published from 2015 to 2025



Source: Compiled by Researchers

Current Status of Products for Visually Impaired Individuals

Overview of Existing Products

To gain a deeper understanding of the types of products available for visually impaired individuals and their current sales status, similar keywords such as "products for visually impaired individuals," "daily necessities for visually impaired individuals," and "assistive tools for visually impaired individuals" were entered into online shopping platforms. According to the research results, a significant number of related products have already been designed and developed.

According to Gu Sumei (Wang Xin et al., 2023), all products can be categorised into five types (as shown in Table 4), broadly divided into five categories: daily living safety, health and medical, electronic communication, entertainment and education, and others. Life safety products include navigation tools (such as guide canes and guide glasses), plastic fruit knives, voice-activated microwave ovens, home-use cup water immersion reminders, and dual-vibration alert shoe inserts; health and medical products include Bluetooth-enabled smart pill boxes; reading and communication products include braille-enabled mobile phones, audiobook players, and visual aids; Entertainment and education products are divided into physical products and application software. Physical products include braille radios, braille Rubik's cubes and playing cards, smart four-in-a-row games, position learning devices, low-vision doorball, and writing boards. Application software primarily consists of voice software and screen-reading software, such as TianTan Screen Reader, Yangguang Screen Reader, and Mind Accessibility Assistant, which meet their needs for text input and voice recognition on mobile devices and computers. Other products include timing devices, such as watches, alarm clocks, and tableware.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 7 Issue 22 (September 2025) PP. 576-595
DOI 10.35631/IJIREV.722032

Table 4: Classification of Existing Products for Visually Impaired Individuals

classification	product
Life safety category	
Health and medical category	
Electronic communication category	
Entertainment and Education	
others	

Source: Organize and create a Table based on visually impaired products on a certain shopping platform

Existing Shortcomings

The product and service system for visually impaired individuals is still underdeveloped. Gu Sumei (Wang Xin, 2023) also mentioned this point in their article, noting that while people worldwide are increasingly providing services for vulnerable groups, human-centered design remains a key focus in the design industry. Zhang Xiaotong (Tian Jingwen et al., 2023) argues that safety assistance tools and basic public facilities specifically designed for them remain limited, while entertainment, education, and cultural products are even more scarce. Products to help visually impaired individuals in China integrate into modern life are severely lagging.

The design of information transmission channels for products for the visually impaired is limited. Existing products on the market that utilise tactile perception are typically designed using Braille. According to data collected by Wu Xinlin (2020) on the physical and mental characteristics and home life of visually impaired individuals in Taizhou City, Jiangsu Province, China, out of 76 valid questionnaires, the majority of respondents had an educational attainment of junior high school or high school, with few highly educated individuals and a significant proportion of illiterate individuals and those with only primary school education. Although some of these individuals have educational backgrounds, many have not received specialised education for the visually impaired. Even those who have had exposure to such education often lack systematic training, preventing them from achieving proficiency in Braille. As a result, visually impaired individuals require extensive training to understand product information.

Specialised products for visually impaired individuals fail to accommodate the daily usage needs of family members. While these products are optimised to address specific needs, they do not consider the daily usage habits of able-bodied family members in terms of operating methods, interaction logic, and functional settings, resulting in insufficient usability and universality. According to Lu Jinyan's (2024) survey results, out of 63 questionnaire responses, only one household was a single individual living alone, while the rest lived with family

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 7 Issue 22 (September 2025) PP. 576-595
DOI 10.35631/IJIREV.722032

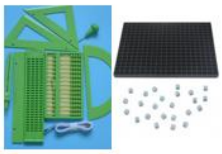
members or caregivers. This living arrangement makes it difficult to meet the actual needs of multiple family members sharing products.

Sensory Compensation Pathways And Applications For Visually Impaired Individuals

Perceptual Pathways Of Existing Visual Impairment Products In The Market

In the human sensory system, vision is the most important means of information acquisition for individuals with intact sensory functions. However, visual impairment necessitates that visually impaired individuals alter their methods of perceiving the world. Beyond external tools, tactile, auditory, and olfactory senses play a crucial role in their daily lives. To further understand the perception pathways of existing products for the visually impaired, researchers selected several products of different types with relatively high sales volumes currently available on the market for detailed analysis. Typical product examples within each category are detailed in Table 5.

Table 5: Perceived Pathways of Visually Impaired Products on an Online Shopping Platform in China

name	Product function	Interaction (perception) mode	Physical drawing
watch	time	Braille	
Smart watch	time	Voice announcement, press buttons	
Timer alarm clock	time	Voice announcement, press buttons	
Auxiliary Braille learning kit	School supplies Write	Tactile sense	
Learning machine	Learning machine	Voice announcement, press buttons	
Toy for the blind	Entertainment product	Braille sense	

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 7 Issue 22 (September 2025) PP. 576-595
DOI 10.35631/IJIREV.722032

Ultrasonic detection navigation equipment blind rod/instrument	Time keeping Wireless search Ultrasonic detector glisten Remote sensing range 20 meters fold	Voice interaction	
Bidirectional vibration ultra-thin reminder insoles	Long-distance transmission 150 meters	Step on the foot, press on the hand	
Multi-functional smart walking stick	illumination charging Music function Automatic fall alarm	key	
Rice cooker for the blind	Cooking tool	Voice announcement, press buttons	
Induction cooker for the blind	Cooking tool	Voice announcement, press buttons	
Quantitative seasoning bottle	Quantitative control seasoning	Voice announcement, press buttons	

Source: Organize visually impaired products on Chinese online shopping platforms and create self-made forms

Guided by the concept of sensory compensation design, existing products for the visually impaired primarily rely on two sensory channels—touch and hearing—to compensate for visual impairments. Through technologies such as vibration feedback, Braille and graphic symbols, and voice interaction, these products have significantly enhanced the environmental perception capabilities and product usage experience of visually impaired users. Although olfactory and gustatory senses could theoretically serve as auxiliary compensation methods, their limited application scenarios and high technical implementation challenges have resulted in few successful cases in actual product design. This has naturally divided existing sensory compensation products into three categories: tactile compensation, auditory compensation, and multisensory integration.

Tactile Perception Methods

Tactile perception is one of the primary sensory channels for visually impaired individuals, enabling them to obtain the most authentic sensations through physical contact with objects. They primarily use their hands and feet to replace their eyes, gathering information about an object's attributes, materials, location, direction, texture (rough or smooth), shape (sharp or rounded), temperature, and size (height, width, and depth).

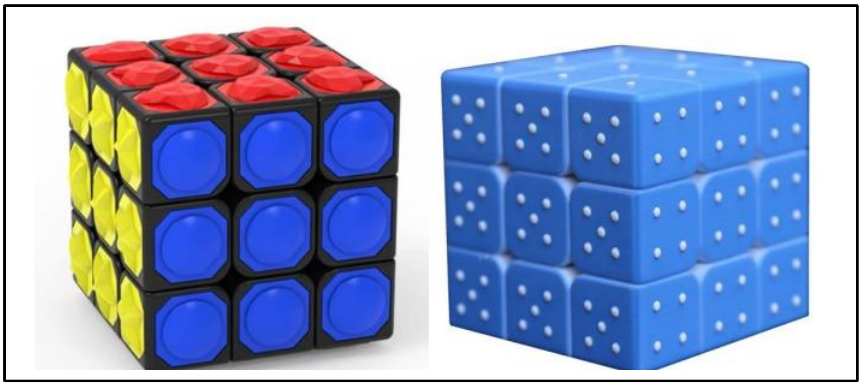
International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 7 Issue 22 (September 2025) PP. 576-595
DOI 10.35631/IJIREV.722032

E. Bruce Goldstein, in his book "Sensation and Perception," describes the cognitive and recognition process of touch from the perspective of human perception. First, when the fingers are stimulated, the sensation is transmitted to the receptors, converted into electrical signals, and then processed by the nervous system. Subsequently, the individual's accumulated knowledge is integrated with prior experiences and memories stored in the brain, forming perceptual information. This information is then used to identify useful information and converted into action-guiding information (Wang Suo, 2020).

The sensory regions of sighted individuals and blind individuals are consistent, but the sensitivity of the index finger region in visually impaired individuals is particularly superior. The sensory threshold value of the fingertips in sighted individuals ranges from 2.2 to 3.0 mm, while the threshold value for visually impaired users is approximately half that of sighted individuals. Visually impaired users primarily rely on their index fingers to perceive most external information (Hu Xinming & Chen Ziyan, 2016).

In design practice, the application of tactile sensory compensation involves designing graphics and Braille that are effective and efficient for visually impaired individuals to touch, using tactile feedback to convey information to this population in place of visual cues. This not only enhances sensory compensation functions but also compensates for the missing sensory capabilities, thereby enabling interactive experiences between individuals and objects. For example, two designs of Rubik's cubes: one features an accessible convex surface with six shapes—flat, star, heart, square, circle, and sunflower—allowing visually impaired individuals to distinguish them effectively through touch. The other design uses Braille convex surfaces.

Figure 5: Two Rubik's Cube Toys with Graphics on The Left and Braille on The Right



Source: A certain online shopping platform

Some scholars have also conducted tests on the tactile preferences of visually impaired students. Wang Shuo (2020) investigated their preferences for dots, solid lines, dashed lines, and contour lines in his master's thesis. In the dot test, it was found that combinations of two dots with a size of less than 1.5 mm and a spacing of 1.5 mm and 2.0 mm were easier to recognise; In the line test, solid lines with a width of 2.0mm were easier to recognise; Finally, they concluded that contour lines in graphics serve as boundary lines between the graphic and the external area, providing a range constraint. Therefore, graphics with contour lines are easier to recognise. This is an important aspect of tactile information design for visually impaired products and provides a solid foundation for designers in subsequent research and development.

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 7 Issue 22 (September 2025) PP. 576-595
DOI 10.35631/IJIREV.722032

Auditory Perception Methods

Auditory perception is the most direct sensory modality for visually impaired individuals and serves as another primary means of compensating for visual impairment. In the design of products for the visually impaired, auditory perception provides a strong sense of security. Sound, as an important medium for information transmission, has dual application value: First, they can provide clear functional guidance through voice prompts and operational instructions. Second, they can establish an intuitive interactive feedback mechanism through non-verbal musical tones and natural sound effects—by designing differentiated sound characteristics (e.g., soft and soothing tones indicating successful operations, and sharp and urgent sounds indicating errors), a multi-layered auditory interaction system with emotional warmth is formed, thereby balancing functionality and user experience.

Research on the auditory experiences of visually impaired individuals reveals that compared to individuals with normal vision, blind individuals possess superior pure-tone pitch discrimination ability (Arnaud et al., 2018; Gougoux et al., 2004; Wan et al., 2010), noise interval recognition ability (Muchnik et al., 1991), auditory segmentation ability (Boroujeni et al., 2017), and sound spatial localization ability (Gougoux et al., 2005; Lessard et al., 1998) in the perception and processing of non-verbal information. When locating and navigating routes, they generally use echoes to measure distances, such as vertical interfaces made of hard materials, where echoes generated while moving through them can assist them in understanding the spatial environment (Jenkins G R et al., 2015; Yoon I et al., 2017; Levy J, 2020).

In developing countries, infrastructure lacks services for visually impaired individuals. In shopping malls, visually impaired individuals rely on their senses to determine their location and identify potential hazards (Mediastika CE et al., 2022). However, efforts are being made to provide more services for visually impaired individuals. For example, at an exhibition, a "multimodal tactile" experiential exhibition was created for visually impaired individuals, featuring an art appreciation platform that integrates multiple senses and synesthesia (CHO, JUN-DONG et al., 2020). During visits to exhibitions, they also collaborate with other senses to convey information about artworks, including touching patterns, scent, and temperature codes.

Care for the visually impaired is also reflected in how they provide danger alerts. With the increasing incidence of household fires, ensuring personal safety and eliminating hazards has become increasingly challenging for visually impaired individuals. Therefore, Minwook Paeng designed a fire extinguisher called "Ball" (please refer to Figure 4.3) specifically for the visually impaired, aiming to help them safely escape dangerous situations. (As shown in the Figure 6), The Ball fire extinguisher is smaller in size than a standard fire extinguisher. It is equipped with a tracking system installed on the body, which works in conjunction with multiple sensors around the room to automatically target the dangerous area and determine the exact location of the fire. The red spherical object on top of the fire extinguisher contains a heat-detecting camera that can automatically rotate to track the fire situation. For visually impaired individuals, the bottom of the cylinder is equipped with a speaker that emits an alarm sound upon a fire and provides voice instructions guiding them to the nearest escape route.

International Journal of Innovation and Industrial Revolution
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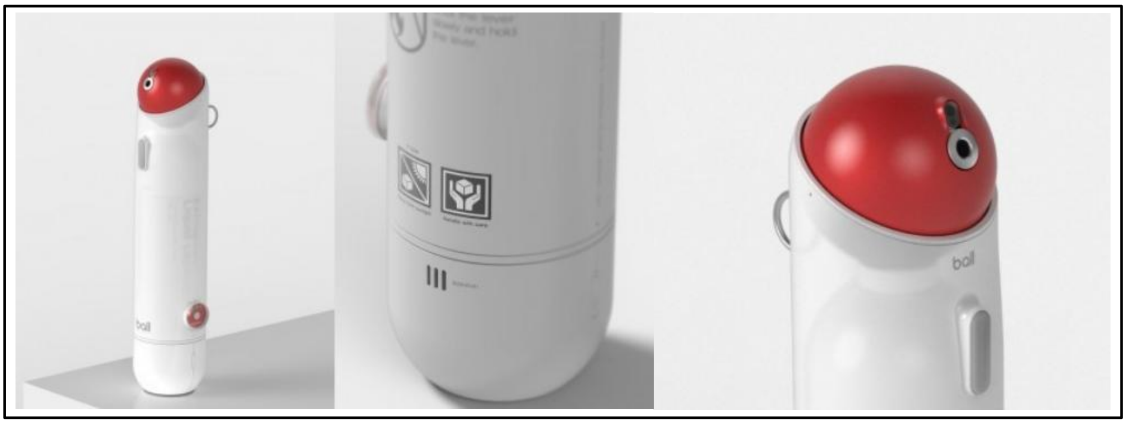
DOI 10.35631/IJIREV.722032

Figure 6: Ball Fire Extinguisher Diagram



Source: Excellent design product official account

Olfactory Detection Method

At the sensory perception level, olfaction is more effective than vision in revealing the essential attributes of objects, rather than merely focusing on superficial characteristics such as form, colour, and size. This characteristic provides a unique compensatory approach for the design of products for the visually impaired—by carefully designing olfactory experiences, it is possible to create special perceptual dimensions that are difficult to achieve through other senses. For example, in product design, scent concentration gradients can be used to construct a spatial perception system, enabling users to determine the distance of objects based on changes in scent intensity. Chen (2021) shares this view, arguing that optimizing visitors' experiences can also rely on olfaction, which is an invisible force that can be linked to people's memories and associations. He notes that the olfactory system's ability to extract and retrieve long-term memories is superior to that of touch and vision. Richard Stevenson (2020) notes that some museums are experimenting with designing exhibitions for visually impaired individuals by incorporating olfactory elements. For example, in Brooklyn, museum tours include specially painted components to explore olfactory visualisation-related works, such as wearable devices and chemical colour-changing agents, and even allow visitors to observe the flow of odors.

There is also an intriguing related study on olfaction. Douglas Polito (2006) first introduced the concept of "smellscape," explaining its emotional impact. German literary critic Daniela Babylon (2017) proposed the "emotional power" of odours. Liu Rurong et al. also explored the artistic thresholds of smellscapes. For example, the Blind Lighthouse Home established in Seattle, USA, in 1970 is actually a botanical garden for the visually impaired, primarily relying on olfactory landscape methods. Additionally, different plants grown in the park emit distinctive odours that help visually impaired individuals locate spatial ranges, identify positions, and provide instructions for determining direction (Hao Weiguo et al., 2021).

Multisensory Integration Approach

In the design of products for the visually impaired, multi-sensory integration and compensation pathways demonstrate unique value and potential. By organically integrating multiple sensory channels such as touch, hearing, and smell, product designers can overcome the limitations of single-sensory compensation and create richer, more immersive user experiences. This comprehensive compensation approach not only includes combinations such as tactile-auditory

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 7 Issue 22 (September 2025) PP. 576-595
DOI 10.35631/IJIREV.722032

and olfactory-auditory integration but, more importantly, requires careful design of the synergistic relationships and information transmission logic between sensory modalities based on the specific characteristics of the usage scenario. When different sensory channels work together in a scientifically reasonable manner, products not only achieve basic functionality but also enhance the pleasure and naturalness of the usage process, enabling blind users to enjoy a more complete and seamless interactive experience. This multi-sensory coordination design approach is opening up new possibilities for accessible product development.

Currently, there are some products that use smart technology as their device platform. For example, a team from Shanghai Jiao Tong University in China released an "AI glasses" (as shown in Figure 7) in 2025. This is a wearable, multimodal (integrating visual, auditory, and tactile systems) visual assistance system designed for visually impaired individuals. It uses artificial intelligence to interpret images captured by cameras installed on the glasses, to map the surrounding environment. When the user approaches an obstacle, the system provides voice prompts through bone conduction headphones and vibration alerts via an expandable "artificial skin" attached to the wrist, guiding them on how to change their route, adjust their direction, and select a safe, accessible path. This device significantly enhances navigation efficiency for visually impaired individuals.

Figure 7: AI Smart Glasses

Source: A Team from Shanghai Jiao Tong University in China is Releasing "AI Glasses" in 2025

Summary

This study is based on a systematic survey of the market for products for the visually impaired and an in-depth study of sensory compensation theory and its applications. It provides a comprehensive analysis of the physiological and psychological characteristics of the visually impaired population and systematically summarises the main sensory compensation pathways and application modes for this group. The study found that sensory compensation design is a design methodology based on the compensatory mechanisms of the human sensory system. This concept originates from the phenomenon of sensory compensation in the medical field, where when one sensory function is lost, other senses enhance their functions to compensate for the loss. Its core characteristics are manifested in three aspects: first, it emphasizes the collaborative design of multiple sensory channels, constructing information transmission systems through alternative interaction methods such as tactile feedback and auditory cues; second, it focuses on the application of neuroplasticity principles to ensure that product interaction modes align with the human brain's sensory compensation mechanisms; and third,

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
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DOI 10.35631/IJIREV.722032

it pursues barrier-free, universal accessibility, ensuring that users with different sensory capabilities can all enjoy a complete product experience.

In the future, sensory compensation design will permeate all aspects of the lives of visually impaired individuals, with its practical value particularly evident in the design of products for the visually impaired. By systematically strengthening the interaction design of non-visual senses, such as optimising the recognisability of tactile identifiers (graphics and Braille) and improving the accuracy of voice feedback, it is possible to effectively solve the interaction barriers that exist in traditional products for the blind. This not only breaks through the limitations of vision-dependent products but also creates a new mode of human-computer interaction that is more inclusive. Additionally, with the deepening of smart sensor technology and human-computer interaction research, the concept of sensory compensation design is evolving toward more refined and intelligent directions. By integrating emerging technologies such as the Internet of Things and artificial intelligence, designers can create more adaptive compensation interaction systems, providing special needs groups with a better product experience. This trend is also driving the evolution of accessibility design concepts from simple functional compensation toward deeper human-computer integration.

This study has its limitations. On the one hand, the literature samples primarily consist of 66 core Chinese and English-language papers published between 2015 and 2025, which may omit important findings in non-mainstream languages and inadequately cover emerging technologies post-2024. On the other hand, the study insufficiently considers the differentiated needs of individuals with multiple disabilities, patients with different causes of blindness, and low-income groups.

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