Spatial Perception in the Blind Population: Knowledge Base, Thematic Evolution, and Multidisciplinary Structure

Presenter：Yuying Wei

Authors: Yuying Wei; Hongyuan Mei*

Harbin Institute of Technology (HIT), China/ 25b934005@stu.hit.edu.cn

2026.09.30

CONTENT

PART 01

Context of the Study

PART 02

Methodology

PART 03

Study Results and Discussion

PART 04

Study Impact and Future Development

Context of the Study



PART 01

Context of the Study

Safe and relatively independent mobility depends on whether environmental information can be acquired, interpreted, and confirmed during action.

- Blindness and visual impairment affect everyday activity organization, access to public services, and participation in social life through their consequences for mobility.
- Wayfinding requires continuous judgements of direction and route choice as a traveller relates the current task to the spatial organization of the environment.
- Buildings, streets, crossings, shared spaces, and transport facilities influence whether landmarks, boundaries, transitions, and other cues remain available along a route.

Wei Y.Y., Mei H.Y. / School Of Architecture And Design, Harbin Institute of Technology / 25b934005@stu.hit.edu.cn

Context of the Study

Blind spatial perception is a multilevel process through which nonvisual cues become spatial knowledge and action.

- The process starts with auditory, tactile, proprioceptive, and residual-vision cues.
- Cue information is organized into knowledge of location, direction, landmarks, spatial relations, route order, and overall layout.
- Spatial knowledge supports orientation, route selection, progress monitoring, and reorientation after deviation.
- Spatial performance varies with visual experience, developmental history, stimulus configuration, task demands, environmental complexity, practice, and feedback continuity.

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Context of the Study

The expansion of research has created a need to understand how separate findings fit into one explanatory structure.

- **Sensory mechanisms** explain how cues are detected.
- **Spatial-learning studies** explain how relations become cognitive maps.
- **Navigation systems** measure performance while a device is operating.
- **Built-environment studies** ask whether spaces remain legible in everyday life.

The review addresses the **scientific task** of explaining **how environmental information becomes spatial knowledge, mobility action, and participation across levels of analysis**.

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Context of the Study

This review maps the field first and then reconstructs a multidisciplinary explanation of its development and future needs.

(1) Describe publication growth in blind spatial perception research and identify leading authors, institutions, countries/regions, and sources.

(2) Identify the journals, documents, and cited authors that constitute the field's shared knowledge base.

(3) Integrate keyword co-occurrence, keyword bursts, and cited-reference clusters to reveal thematic structure, research hotspots, and their changes over time.

(4) Examine the distribution of disciplinary participation and the connections among disciplines.

(5) Reconstruct the mapping results as a traceable multidisciplinary knowledge structure.

(6) Identify critical gaps between research themes and propose directions for future work.

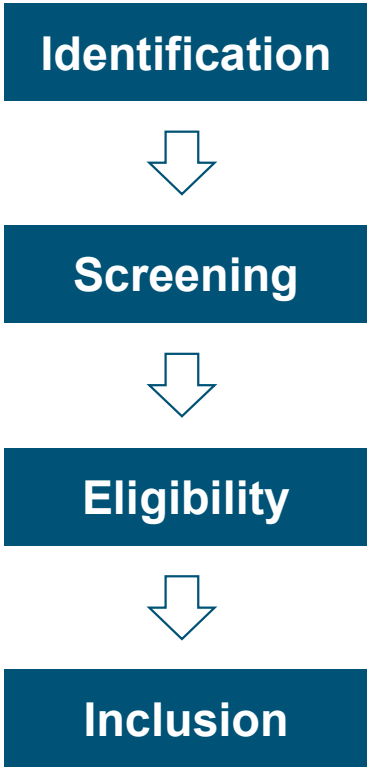
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Methodology

PART 02

Methodology

Thematic group	Search terms (TS)
Population terms	"blind*" OR "people who are blind" OR "persons who are blind"OR "the blind" OR "blindness" OR "congenital blindness" OR "acquired blindness" OR "early blind*" OR "late blind*" OR "visual impairment*" OR "visually impair*" OR "vision impairment*" OR "low vision" OR "sight loss"
Spatial-process terms	"spatial percep*" OR "spatial cognit*" OR "spatial represent*" OR "spatial knowledge" OR "spatial memory" OR "spatial learning" OR "spatial orientation" OR "spatial awareness" OR "spatial updating" OR "spatial abilit*" OR "cognitive map*" OR "reference frame*" OR "environmental percep*" OR "environmental cognit*" OR wayfind* OR "way finding" OR navigat* OR "orientation and mobility" OR "independent mobility" OR "mobility training" OR "route learning" OR "route knowledge" OR "route guidance" OR "auditory localization" OR "sound localization" OR "spatial hearing" OR echolocation OR "haptic spatial*" OR "tactile spatial*" OR "tactile map*"



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Methodology

CiteSpace 7.0.R0 was used to analyse collaboration, co-citation, conceptual change, knowledge clusters, and disciplinary participation.

Parameters	Settings
Software	CiteSpace 7.0.R0
Input data	1,265 records
Time slicing	2000–2026; 1 year per slice
Node types	Cited reference, cited author, cited journal, cited institution, cited country, WoS subject category and keywords
Analyses	Collaboration, co-citation, keywords co-occurrence and bursts and clustering

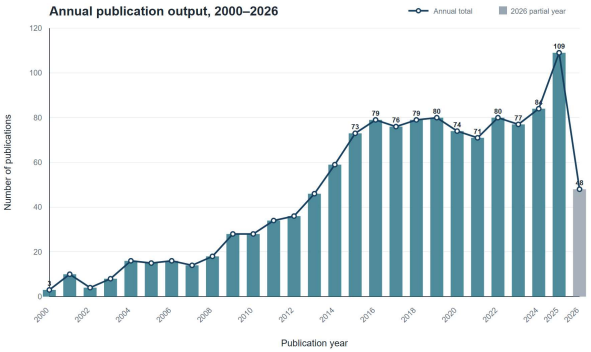
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Study Results and Discussion

PART 03

Growth and collaboration structure

- Research output expanded sharply after 2016.
- Author and institutional networks show stable local teams centred on spatial cognition and assistive technologies.
- The country or region network is internationally broad.



Annual publication output



Country/region collaboration network



Institutional collaboration network



Author collaboration network

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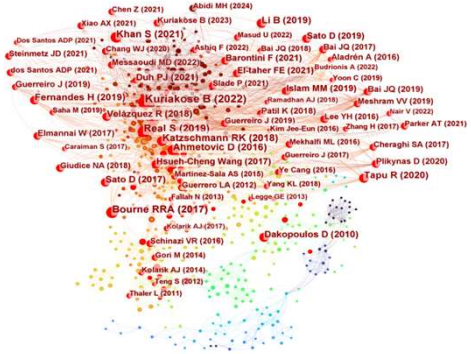
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Co-citation knowledge base

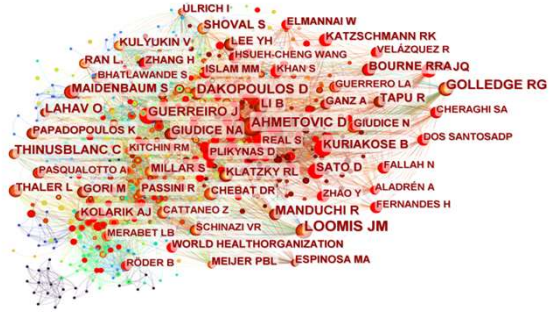
- The most frequently co-cited sources include Lecture Notes in Computer Science, Journal of Visual Impairment & Blindness, Sensors, PLOS ONE, and the CVPR proceedings.
- Document and author co-citation show that influential work is distributed across spatial cognition, electronic travel aids, accessibility computing, and nonvisual learning.



Co-citation network of cited journals



Co-citation network of cited journals



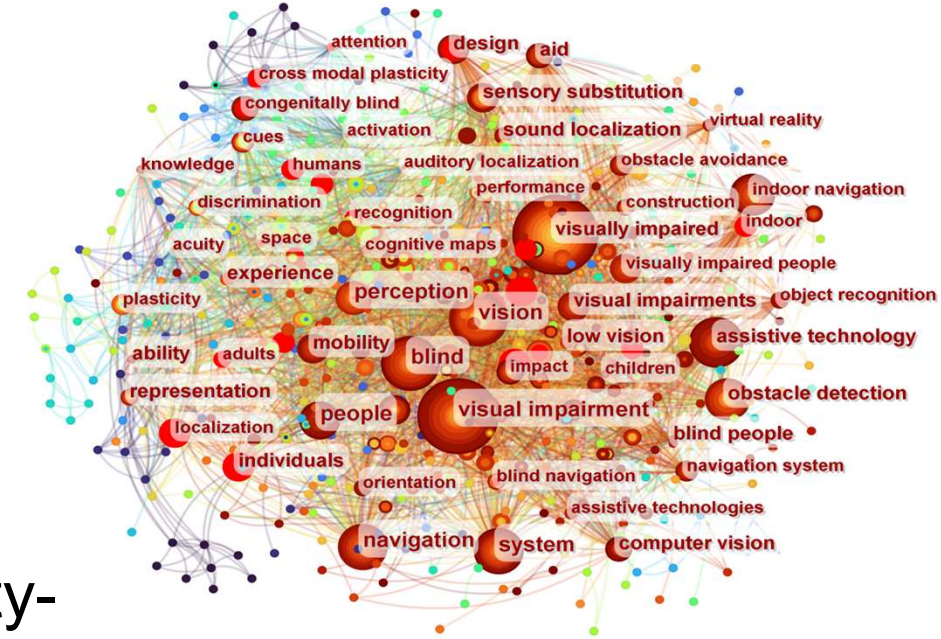
Co-citation network of cited authors

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Keywords co-occurrence and the information chain

- The keyword network reveals a continuous information chain from sensing to action.
- Frequent terms: **visually impaired, visual impairment, blind, assistive technology, navigation, indoor navigation, obstacle detection, perception, and orientation and mobility**.
- Application pathway: sensing modality-localization detection-positional judgement-multimodal feedback-navigation action.



Keywords co-occurrence network

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Temporal evolution of research fronts

Citation bursts show a movement from perceptual mechanisms toward intelligent and functionally oriented mobility support.

From 2017 onward, blind navigation, localization, and recognition became stronger fronts associated with real-time mobility support.

The most recent fronts include technology, deep learning, artificial intelligence, smart cane, and orientation and mobility.

Top 20 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2000 - 2026
visual cortex	2000	5.26	**2000**	2014	
attention	2000	4.87	**2000**	2011	
performance	2001	6.2	**2001**	2012	
cross modal plasticity	2005	5.19	**2005**	2015	
congenitally blind	2005	4.69	**2005**	2012	
humans	2006	5.22	**2006**	2017	
perception	2010	6.42	**2010**	2016	
tactile map	2010	4.22	**2010**	2015	
visually impaired	2001	4.47	**2012**	2015	
space	2002	4.56	**2013**	2017	
blind navigation	2008	4.28	**2017**	2019	
localization	2012	5.81	**2019**	2022	
recognition	2011	4.65	**2019**	2022	
technology	2020	4.84	**2020**	2024	
deep learning	2020	3.95	**2020**	2026	
individuals	2019	3.85	**2020**	2026	
orientation and mobility	2009	6.67	**2022**	2026	
artificial intelligence	2020	4.99	**2024**	2026	
adults	2006	3.95	**2024**	2026	
smart cane	2024	3.79	**2024**	2026	

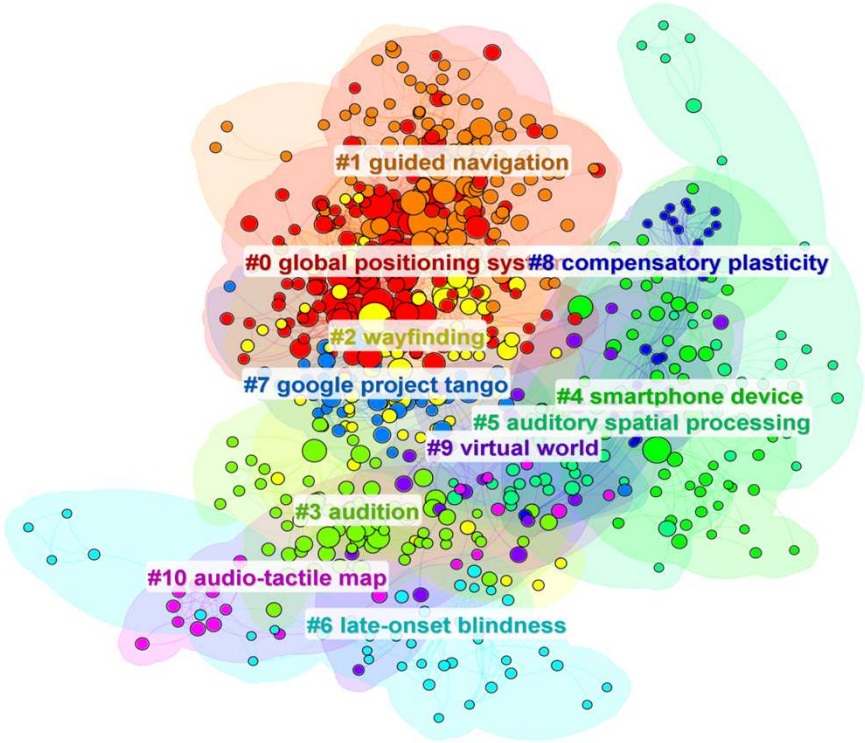
Keywords co-occurrence network

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Results and Discussion

Cited-reference clusters

- Eleven cited-reference clusters provide a relatively stable domain structure for the field.
- The largest clusters are labelled **global positioning system, guided navigation, wayfinding, audition, auditory spatial processing, smartphone device, late-onset blindness, Google Project Tango, compensatory plasticity, virtual world, and audio–tactile map.**



Cited-reference cluster network

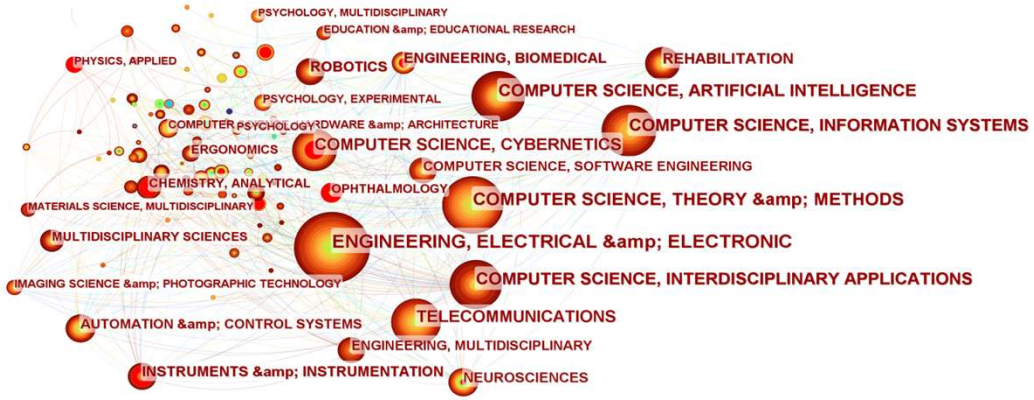
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Results and Discussion

Disciplinary network

- The disciplinary network is connected overall, but participation is strongly uneven.
- Engineering, Electrical & Electronic ranks first with 322 records.



WoS subject-category network

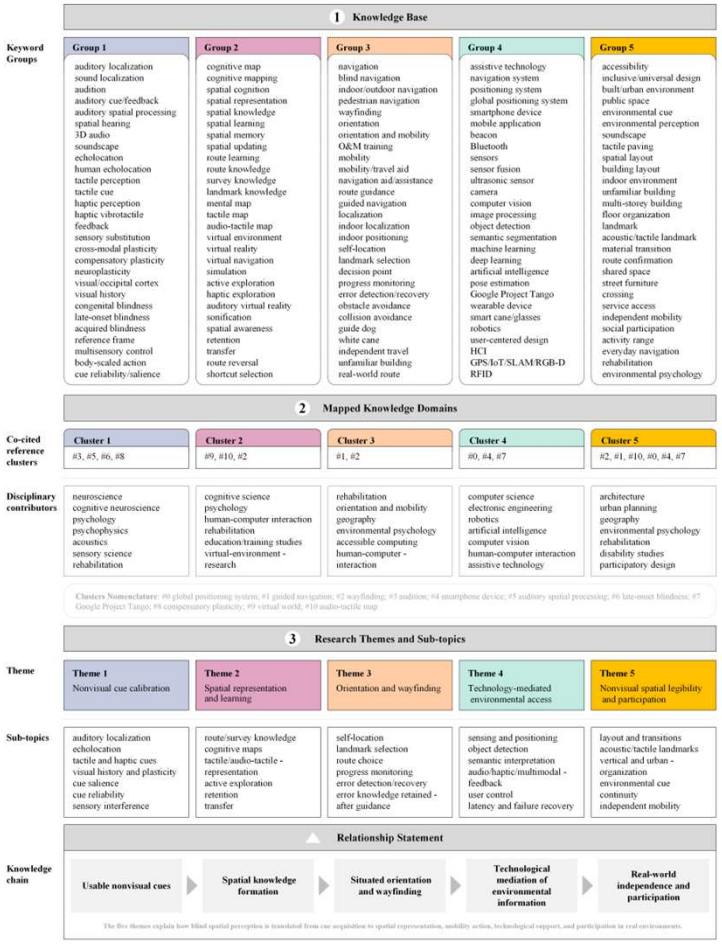
- Built-environment and spatial-planning categories are present but less prominent.
- The field is multidisciplinary but technologically centred, with the built environment still weakly coupled to the dominant network.

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Results and Discussion



Five-theme multidisciplinary knowledge structure

- 1. Nonvisual cue calibration
- 2. Spatial representation and learning
- 3. Orientation and wayfinding
- 4.Technology-mediated environmental accessibility
- 5. Nonvisual spatial legibility and social participation
- cue calibration - spatial knowledge - wayfinding action - technology mediation - environmental legibility and participation

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Results and Discussion

Theme 1 — Nonvisual cue calibration

- Cue utility is jointly regulated by visual experience, neural plasticity, task context, stimulus configuration, and practice.
- Auditory, tactile, echolocation, and multimodal signals become usable spatial references when they have sufficient salience, directionality, reliability, and continuity.

Theme 2 — Spatial representation and learning

- Spatial knowledge is not a simple accumulation of cues; it is the organization of positional relations, route order, landmark structure, and overall layout.
- Active exploration and tactile or audio–tactile maps preserve the coupling between bodily movement and environmental feedback.

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Results and Discussion

Theme 3 — Orientation and wayfinding

- Travelers establish their location and heading, identify relevant landmarks and spatial transitions, select or confirm a route, monitor expected and actual information, and reorient after deviation.
- Architecture, environmental psychology, rehabilitation, and accessibility computing all contribute to this process.

Theme 4 — Technology-mediated environmental accessibility

- Navigation systems transform environmental states into action-relevant information through sensing, algorithmic processing, and interface encoding.
- GPS, beacons, indoor positioning, computer vision, semantic recognition, glasses, canes, and robots support different stages of this transformation.

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Theme 5 — Nonvisual spatial legibility and social participation

- Nonvisual spatial legibility refers to the degree to which continuity in environmental layout, spatial transitions, landmarks, acoustic properties, and tactile cues helps users construct, verify, and use a spatial model during action. It connects the knowledge chain to the built environment and everyday participation.
- Clear relational information allows users to integrate local cues into a relatively stable understanding of the environment.
- Inconsistent street facilities, shared streets, unstable acoustics, poorly expressed multilevel relations, and weak route continuity make it difficult to verify current position, direction, and next action.

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Cross-theme gaps

①Nonvisual mechanisms are rarely tested in complex real-world mobility.

②Navigation assistance and spatial learning are usually evaluated separately.

③ Assistive technology and environmental legibility are rarely manipulated together.

④Short-term travel improvement is seldom connected to long-term participation.

⑤Disciplines use different variables and lack a shared reporting basis.

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Study Impact and Future Development

PART 04

Study Impact and Future Development

Study impact

- **Theoretically**—The framework connects perceptual mechanisms, spatial cognition, wayfinding behaviour, assistive technologies, environmental conditions, and social participation by distinguishing how environmental information is detected, organized, used for action, and linked to longer-term outcomes.
- **Practically**—The framework gives architecture, planning, rehabilitation, O&M, engineering, and HCI a common basis for evaluating landmarks, spatial continuity, recovery, and sustained use alongside detection and localization accuracy.
- **Scalability**—The five-theme structure can be translated into shared protocols and reporting variables for cross-site evaluation across buildings, streets, devices, and service settings.

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Study Impact and Future Development

Future development

- Shared analytical units should include landmarks, boundaries, transition nodes, and decision points.
- Shared outcome measures should include safety, spatial learning, orientation confidence, cognitive burden, recovery from deviation, independent mobility, and social participation.
- Studies should examine indoor–outdoor transitions, vertical circulation, large buildings, complex intersections, and acoustically unstable spaces.
- Longitudinal mixed-methods studies should connect short-term system performance with training, maintenance, adaptation, activity space, discontinuation, and participation over time.

Study Impact and Future Development

Conclusion and limitation

- Its knowledge base is multidisciplinary, but author and institutional collaboration remains clustered and the built environment remains weakly coupled to the technical centre.
- The five themes organize the field as a chain from cue calibration and spatial learning to wayfinding, technology-mediated accessibility, environmental legibility, and participation.
- The dataset contains English-language records indexed in WoSCC, and 2026 records were counted only through July.
- Network structures, burst terms, and clusters are influenced by database coverage, node selection, and parameter settings; the framework therefore requires multi-database replication and cross-disciplinary empirical testing.

Wei Y.Y., Mei H.Y. / School Of Architecture And Design, Harbin Institute of Technology / 25b934005@stu.hit.edu.cn

THANKS FOR WATCHING

Presenter：Yuying Wei

Authors: Yuying Wei; Hongyuan Mei

Harbin Institute of Technology (HIT), China/ 25b934005@stu.hit.edu.cn