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REVIEW

Technological and design interventions for independent public transport use by people with visual impairments

Intervenciones tecnológicas y de diseño para el uso independiente del transporte público por personas con discapacidad visual

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ABSTRACT

Introduction: Blind and low-vision individuals continue to encounter substantial barriers when accessing public transportation. Although technological solutions and design strategies have been developed to improve accessibility, their effectiveness has not been comprehensively synthesized. Methods: A systematic review was conducted in accordance with PRISMA 2020 guidelines. The methodological quality of included studies was assessed using the Mixed Methods Appraisal Tool (MMAT), and findings were integrated through a narrative synthesis structured according to the outcome hierarchy. Results: Of 912 records identified, 703 underwent screening, and 10 studies met the inclusion criteria. For the primary outcome, encompassing wayfinding and environmental detection, vehicle and route identification accuracy ranged from 96.89% to 100%, while in-station sign detection reached 0.97. An electronic travel aid also reduced cane use and collisions among 13 participants. Regarding secondary outcomes, perceived accessibility of a transit plaza ranged from 72% to 89%, while interface redesign improved task completion in simulated scenarios and reduced errors. Conclusions: Technological interventions demonstrate high levels of technical accuracy; however, only six studies included individuals with visual impairments in outcome assessments. Consequently, confidence in their effectiveness for supporting independent public transport use remains limited. Future research should prioritize direct assessments of users' travel behaviour and functional performance in real-world mobility settings.

Keywords: visual impairment; blindness; public transport; wayfinding; assistive technology; accessibility.

RESUMEN

Introducción: Las personas ciegas o con baja visión enfrentan barreras persistentes para utilizar el transporte público. Aunque se han desarrollado diversas soluciones tecnológicas y propuestas de diseño orientadas a mejorar la accesibilidad, sus resultados aún no se han sintetizado de manera integral. Métodos: Se realizó una revisión sistemática siguiendo las directrices PRISMA 2020. La calidad metodológica de los estudios incluidos se evaluó mediante la herramienta Mixed Methods Appraisal Tool (MMAT), y los resultados se integraron mediante una síntesis narrativa organizada según la jerarquía de los desenlaces. Resultados: Se identificaron 912 registros, de los cuales 703 fueron sometidos a cribado y 10 estudios cumplieron los criterios de inclusión. En el desenlace principal, relacionado con la orientación espacial y la detección de elementos del entorno, la precisión para identificar vehículos y rutas osciló entre el 96,89 % y el 100 %, mientras que la detección de señales en estaciones alcanzó un valor de 0,97. Asimismo, una ayuda electrónica para la movilidad redujo el uso del bastón y las colisiones en 13 participantes. Entre los desenlaces secundarios, la accesibilidad percibida de una plaza de transporte osciló entre el 72 % y el 89 %, mientras que el rediseño de interfaces incrementó la finalización de tareas simuladas y disminuyó los errores. Conclusiones: Las intervenciones tecnológicas muestran una elevada precisión técnica; sin embargo, únicamente seis estudios incorporaron a personas con discapacidad visual en la medición de resultados. En consecuencia, la certeza de la evidencia sobre sus efectos en la autonomía durante el uso del transporte público sigue siendo baja. Las investigaciones futuras deberán priorizar evaluaciones directas del comportamiento y desempeño de los usuarios durante sus desplazamientos.

Palabras clave: discapacidad visual; ceguera; transporte público; orientación espacial; tecnología de asistencia; accesibilidad.

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INTRODUCTION

People who are blind or have low vision depend on public transport more than the general population, yet the built and digital environments of transit systems remain oriented toward sighted users.(1)

An estimated 43 million people worldwide were blind and a further 295 million had moderate or severe vision impairment in 2020, and most lived in low and middle income countries where accessible transport infrastructure is scarcest.(2)

For these travellers, the journey chain that links trip planning, walking to a stop, waiting, boarding, riding and alighting is interrupted at multiple points by information that is presented only visually, by uneven or obstructed walking surfaces, and by the absence of consistent audible or tactile cues.(1,3)

Surveys of blind and low vision adults describe the same recurring failures: stops whose identity cannot be confirmed from the vehicle, vehicles that arrive without audible route announcements, and stations in which braille signs exist but are placed where they cannot be found.(1,3)

The consequence is measurable: persons with visual impairments report elevated stress during transit use and reduced independent mobility, which restricts employment, health care and social participation.(4,5)

In response, two broad families of intervention have developed. The first family comprises technological aids, including smartphone navigation applications, computer vision systems that detect vehicles and route numbers, Bluetooth beacons and electronic travel aids that convert spatial information into audio or haptic output.(6,7)

More recently this family has incorporated artificial intelligence, with adaptive assistants that describe the environment, collective intelligence across internet of things devices and behaviour adaptive interfaces that respond to individual users, all of which remain mostly at the prototype stage.(8-11)

The second family comprises design interventions embedded in infrastructure, such as tactile paving, braille signage, audible announcements and the physical configuration of stations and transit plazas.(12,13)

Systematic reviews of wayfinding and mobility technologies have been published, but they concentrate on general pedestrian navigation rather than on public transport specifically, and they rarely separate the two families of intervention.(14-16)

A scoping review of access to public transport for people with visual disability confirmed that intervention studies are scarce and heterogeneous, which prevents decision makers from distinguishing what works from what has merely been prototyped.(12)

The primary outcome of interest in this review is wayfinding and detection performance, defined as the accuracy with which a technological or design intervention lets a traveller locate, identify or move through the elements of a public transport journey, and the secondary outcomes are usability, satisfaction, perceived safety and reported travel independence.

The distinction matters because technical accuracy does not automatically translate into independent use by people with visual impairments, a gap documented repeatedly in assistive technology research.(17,18)

Studies of walking environments also show that physical barriers and tactile surfaces condition what any assistive device can achieve, which makes the interaction between technology and infrastructure part of the outcome rather than a constant background.(19,20)

Several recent systems report near perfect detection in controlled conditions, but few are tested with the intended users, and even fewer measure whether travel behaviour changes.(21,22)

Needs assessments in diverse cities repeat the same finding: users ask for reliable orientation information and warning signals more than for additional sensing capacity.(23,24)

The objective of this systematic review was to synthesize the evidence on technological and design interventions intended to improve the independent use of public transport by people with visual impairments.

The review question was which technological and design interventions improve that independent use, examined through the primary outcome of wayfinding and detection performance and the secondary outcomes of usability, satisfaction, perceived safety and independence. The review deliberately included both technical validations and user centred evaluations, so that the distance between what a system detects and what a user accomplishes could be made visible, and it restricted its scope to the public transport journey while drawing on the wider wayfinding literature for interpretation rather than for evidence.

METHODS

This review followed the PRISMA 2020 statement and the PRISMA-S extension for reporting literature searches.(25,26)

Eligibility was defined with the PICOS elements. The population comprised people who are blind or have low vision, including users of white canes, guide dogs and residual vision. The intervention comprised any technological aid, such as a smartphone application, computer vision or beacon system, or any design intervention, such as tactile paving, braille signage, audible announcements or station configuration, intended to improve a stage of the public transport journey from trip planning to alighting.

The comparator was usual practice, no aid, or an alternative intervention. The outcomes were wayfinding and detection performance as the primary outcome, and usability, satisfaction, perceived safety and reported independence as secondary outcomes. Eligible designs included technical validations, usability studies, field evaluations, surveys and mixed methods studies, and grey literature was admissible when it reported an empirical evaluation, which allowed the inclusion of one institutional report.

Studies were excluded when the population did not include people with visual impairments, when the intervention did not target public transport, when no outcome was measured, when the record was a review, editorial or study protocol, or when the report duplicated an already included study. The bibliographic window was 2013 to 2026, consistent with the target volume, and no language restriction was applied.

Information sources and search strategy

Scopus, OpenAlex, Crossref and Semantic Scholar were searched. The core query combined population, transport and intervention terms, for example TITLE-ABS-KEY(“visual impairment” OR “visually impaired” OR blind OR “low vision”) AND TITLE-ABS-KEY(“public transport” OR transit OR bus OR metro OR subway OR “railway station”) AND TITLE-ABS-KEY(navigation OR wayfinding OR orientation OR mobility).

Four additional core queries broadened the intervention vocabulary to wayfinding, assistive technology, mobile applications, beacons, tactile paving, audible announcements and navigation aids, and four supporting queries targeted travel barriers, wayfinding outside transport, tactile maps and public transport accessibility for disability. All searches restricted publication year to 2013 to 2026, and each query was saved with its date and record count so that the strategy could be reproduced.

Study selection

Records were deduplicated by the retrieval tool and screened in two stages. At the title and abstract stage, records were classified as potentially eligible or excluded, and at the full text stage potentially eligible records were assessed against the eligibility criteria. Records whose title and abstract did not allow a decision were carried forward to full text rather than excluded for lack of information.

Full texts were retrieved only from legitimate open access locations, and records without an open access full text were recorded as not retrieved, with the reason preserved. The PRISMA flow diagram was generated from the recorded counts and was not adjusted by hand.

Data extraction

For each included study, one reviewer extracted study design, country, population, sample size, intervention, comparator, outcome and the main result, together with its location in the full text. Extraction recorded whether the outcome data came from people with visual impairments or from technical testing alone, because that distinction determined the placement of each study in the outcome hierarchy. The data items were chosen before extraction and were applied identically to all studies, so that a technical validation and a qualitative evaluation would contribute the same fields and the same rule for incomplete information. Fields without evidence in the retrieved text were left blank rather than completed by assumption.

Synthesis methods

Results were synthesized narratively and ordered by outcome hierarchy. The primary outcome was wayfinding and detection performance, the secondary outcomes were usability, satisfaction, perceived safety and reported independence, and additional analyses examined intervention ca-

tegory and the presence of users with visual impairments in outcome measurement. For each outcome domain, studies were grouped by whether the result came from technical testing or from users with visual impairments, and the grouping was used to judge how much weight the result could bear.

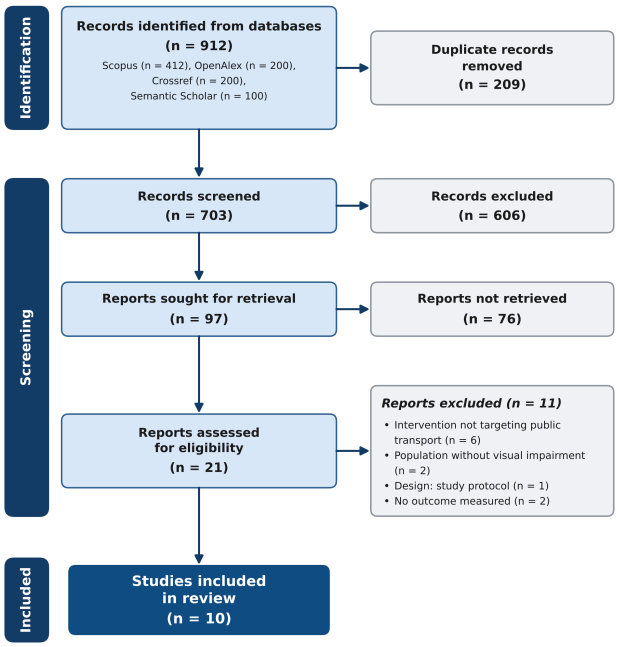
RESULTS

Study selection

The database searches identified 912 records, of which 209 were duplicates, leaving 703 records screened at the title and abstract stage (Figure 1). Scopus contributed 412 of the identified records, OpenAlex and Crossref contributed 200 each, and Semantic Scholar contributed 100. Of the 703 screened records, 606 were excluded and 97 reports were sought for retrieval. Full texts could not be retrieved for 76 reports because no open access version was available or the publisher blocked automated download.

The remaining 21 reports were assessed for eligibility, and 11 were excluded: six because the intervention did not target public transport, two because no outcome was measured, two because the population did not have visual impairments, and one because the record was a study protocol. Ten studies were included in the review.

Figure 1. PRISMA 2020 flow diagram of study selection.



Characteristics of included studies

The ten included studies were published between 2018 and 2026 and originated from eight countries: Indonesia contributed three studies, and Austria, Denmark, India, Switzerland, Thailand, Ukraine and the United States contributed one each (Table 1). Four studies were technical validations of a system or model, one was a comparative evaluation of electronic travel aids, three were qualitative evaluations, one was a user centred design study and one was a mixed methods survey.

The interventions covered six categories: navigation within stations, identification of vehicles and route numbers, station and stop accessibility design, a transport booking interface, electronic travel aids for wayfinding, and system design dimensions. Six of the ten studies collected outcome data directly from people with visual impairments, and sample sizes were small or unreported in every study.

The station navigation studies addressed the middle mile problem of moving through a transit hub. Commute Booster combined the general transit feed specification with optical character

recognition to read the directional signs that a traveller encounters inside New York City subway stations and to announce them in real time.(28)

The Copenhagen study evaluated the wider information environment of a transit network, comparing the information available to sighted commuters with what blind and partially sighted commuters could access, and it recommended audio announcements, beacon technology and stricter operator regulation as the highest value improvements.(29)

The vehicle identification studies addressed the moment of boarding: one model detected the bus, its door and its route number from a video sequence and returned a voice instruction, a second classified the smartphone viewpoint from which an approaching bus number could be read, and a third used YOLOv8 with optical character recognition and offline speech synthesis to detect vehicles and route numbers at stops.(30-32)

The station design studies evaluated physical accessibility: one appraised a refurbished transit plaza in Jakarta against technical standards and the experience of users with visual impairments, and one surveyed tactile orientation media across three train stations in Bandung.(33,34)

The remaining studies examined a transport booking interface, a tramway system as a whole and a pair of electronic travel aids.(13,35,36)

Table 1. Characteristics of the ten included studies.

Study	Country	Design	Intervention	Outcome	Main result
Feng et al., 2023(28)	United States	Technical validation	Commute Booster app (GTFS + OCR) for in-station navigation	Sign detection accuracy	0.97 accuracy; 11 m range
Ponnada et al., 2021(30)	India	Technical validation	Computer vision model for bus door and route number	Detection accuracy	96.89%
Bonita and Lukman, 2021(33)	Indonesia	Qualitative evaluation	Refurbished transit plaza	Perceived accessibility	72-89% by segment
Paul et al., 2018(29)	Denmark	Qualitative evaluation	Accessible transit information	Information accessibility	Recommendations only
Tangsuksant et al., 2018(31)	Thailand	Technical validation	Smartphone viewpoint classification	Viewpoint classification	Successful; 8.70% error
Zahib et al., 2022(35)	Indonesia	User centred design	Redesigned transport booking app	Completion and errors	Completion up; errors down
Fadhlillah, 2022(34)	Indonesia	Mixed methods survey	Tactile orientation media in stations	Accessibility level	Minimum services not met
Barkovska et al., 2025(32)	Ukraine	Technical validation	YOLOv8 + OCR + text to speech app	Detection accuracy	100%; lower in low visibility
Mimra et al., 2025(13)	Austria	Qualitative mixed methods	Tramway system and accessible design dimensions	Accessibility dimensions	Two-sense principle valued
Pittet et al., 2026(36)	Switzerland	Comparative evaluation	Electronic travel aids (NOA and BuzzClip)	Cane use and collisions	Reduced with NOA

Note: NR = not reported; BVI = blind and visually impaired.

Risk of bias

Methodological appraisal indicated high risk of bias across all included studies (Table 2). The technical validations did not involve users with visual impairments in outcome measurement, so their accuracy figures do not establish effects on independent use. The six studies that involved the target population used small or unreported samples, and the comparative evaluation of electronic travel aids did not describe blinding. No study randomized participants or controlled for confounding, and none reported a pre registered analysis.

For the qualitative evaluations, the appraisal raised concerns about the adequacy of sampling and about whether the interpretation was grounded in the participants accounts rather than in the researchers expectations. For the technical validations, the main concerns were the absence of user outcome data and the reporting of accuracy under favourable conditions without a stress test, with the single exception of the Ukrainian system that was evaluated under adverse weather.

Table 2. Methodological appraisal of the included studies.

Study	Design	BVI users in outcome data	Sample	Overall risk
Feng et al., 2023(28)	Technical validation	No	3 stations	High
Ponnada et al., 2021(30)	Technical validation	No	NR	High
Bonita and Lukman, 2021(33)	Qualitative evaluation	Yes	NR	High
Paul et al., 2018(29)	Qualitative evaluation	Yes	NR	High
Tangsuksant et al., 2018(31)	Technical validation	No	Roadside scenarios	High
Zahib et al., 2022(35)	User centred design	Yes	NR	High
Fadhlillah, 2022(34)	Mixed methods survey	Yes	30	High
Barkovska et al., 2025(32)	Technical validation	No	Simulated conditions	High
Mimra et al., 2025(13)	Qualitative mixed methods	Yes	NR	High
Pittet et al., 2026(36)	Comparative evaluation	Yes	13	High

Note: BVI = blind and visually impaired. Overall risk was assigned conservatively.

Primary outcome: wayfinding and detection performance

Four studies reported the primary outcome as technical detection accuracy. In the Commute Booster evaluation, in-station sign detection achieved an overall accuracy of 0.97 across three New York City subway stations, with a maximum detection range of 11 metres and an oblique field of view of approximately 110 degrees.(28)

Detection accuracy of 96.89 percent was reported for a computer vision model that identified the bus, its door and its route number,(30)and detection accuracy of 100 percent was reported for a YOLOv8 based application that recognized public transport vehicles and route numbers at stops under real and simulated weather conditions, although recognition robustness decreased under low visibility.(32)

For the viewpoint classification method intended to orient a smartphone toward an approaching bus, the classification was reported as successful across roadside scenarios, with a reference line error of 8.70 percent.(31)

One study measured the primary outcome as human wayfinding behaviour: in a comparison of two electronic travel aids, 13 participants with blindness or low vision used their canes less and collided less with obstacles when using one device than when using the other.(36)No study reported trip completion or travel frequency by users with visual impairments.

The technical figures were obtained under different conditions, which limits direct comparison. The 0.97 sign detection accuracy of Commute Booster was measured in three real subway stations but without participants with visual impairments, and it describes the recognition of signs rather than the completion of a journey.(28)

The bus door model of Ponnada and colleagues was validated in case studies under several scenarios and reported its accuracy for the combined task of locating the vehicle, its door and the boarding path, yet the number of test instances was not reported.(30)

The Ukrainian application was the only system tested under adverse weather, and its authors stated explicitly that recognition robustness decreased under low visibility, which is a more informative result than the ceiling accuracy of 100 percent obtained in clear conditions.(32)

The viewpoint classification method reported its result as a success criterion for roadside scenes and as an error term for the reference line rather than as a participant level outcome.(31) In the comparative evaluation, the improvement in cane use and collisions was measured in a controlled obstacle task rather than in a transit journey, so its transfer to public transport remains to be demonstrated.(36)

Across the five studies, the primary outcome therefore advanced from proof of detection to proof of concept, but it stopped short of the behaviour that the review set out to measure.

Secondary outcomes: usability, satisfaction, safety and independence

Among secondary outcomes, perceived accessibility of a refurbished transit plaza in Jakarta ranged from 72 percent to 89 percent across six segments, and people with visual impairments

described mobility within the plaza as easy and safe although convenience differed from the technical standard.(33)

After a user centred redesign of a transport booking application, scenario completion increased and the number of errors decreased relative to the previous interface.(35)

In the evaluation of tactile orientation media at three train stations, 30 people with visual impairments reported that minimum service standards were not met and that universal design principles had not been applied.(34)

The qualitative evaluation of transit information in Copenhagen concluded that accessible information depended on audio announcements, regulation of bus operators, accessible mobile applications and beacon deployment, but it did not quantify an effect.(29)

A mixed methods study of visually impaired tramway passengers found that accessibility emerged from interactions between passengers, staff, devices and infrastructure, and that the two sense principle, with directional audio and tactile feedback, was particularly valued for warning signals.(13)

The direction of the secondary findings was consistent even where the magnitudes were not quantified. The transit plaza evaluation showed that a design intervention can meet technical accessibility standards while still falling short of user convenience, because the same segment was scored differently on compliance and on experience.(33)

The booking application redesign showed that interface simplification and features designed around the needs of blind users improved task performance, although the number of participants and the magnitude of the improvement were not reported.(35)

The train station survey showed that the presence of tactile media was not enough when the media had been designed around a visual logic and still relied on assistance from other people, a finding that echoes the Copenhagen recommendation to make information independently accessible.(29,34)

Taken together, the secondary outcomes describe a consistent pattern: design and user centred interventions moved user experience in the intended direction, while purely technical interventions provided no information about experience at all.

Additional analyses

When studies were grouped by intervention category, vehicle and route identification accounted for three studies, station navigation and information for two, station and stop accessibility design for two, and transport booking, electronic travel aids and system design dimensions for one study each (Table 3). Consistently, the studies that measured users with visual impairments reported the most cautious results, whereas the technical validations reported near ceiling accuracy without user outcome data. No study provided data for a quantitative comparison between intervention categories.

Grouped by geography, the included studies concentrated in middle income countries, with three studies from Indonesia and one each from India, Thailand and Ukraine, while high income countries contributed four studies. This distribution reflects where open access technical development is most active rather than where the population of blind and low vision travellers is largest, and it means the synthesis under represents sub-Saharan Africa and Latin America, where accessible transit evidence is scarcest.

Grouped by the involvement of users, the six studies that collected outcome data from people with visual impairments were exclusively the design, qualitative and comparative studies, and none of the four technical validations reported any user measurement. The pattern suggests that the field treats technical validation and user evaluation as separate activities rather than as stages of a single evaluation pathway.

Special considerations

Two features of the evidence base deserve explicit note. The first is the high proportion of reports that could not be retrieved: 76 of the 97 reports sought were unavailable as open access full text, and several of those, including evaluations of outdoor navigation assistance and of orientation and mobility in bus and subway networks, were directly on topic.

Their absence could not be filled by any of the included studies, and it means the primary outcome may over represent systems whose developers published open access technical reports rather than systems tested with users. The second feature is the absence of reported adverse effects or missing data across the included studies: none of the ten reports described harm, device abandonment or data loss, which is unlikely to reflect a genuinely risk free technology and more

plausibly reflects the early stage and brevity of the evaluations. Both features reinforce the need to interpret the reported accuracies as promising rather than as evidence of effectiveness.

Table 3. Synthesis of findings by outcome domain.

Outcome domain	Studies	Reported result
Wayfinding and detection performance	5(28,30-32,36)	Accuracy 0.97 to 100%; reduced cane use and collisions
Usability and satisfaction	3(13,33,35)	Completion up; accessibility 72-89%; two-sense principle valued
Perceived safety and independence	2(29,34)	Standards not met; recommendations only

DISCUSSION

The principal finding of this review is that technological interventions for public transport access by people with visual impairments achieve high technical accuracy, with detection figures between 96.89 percent and 100 percent, while the evidence that these systems improve independent use by the intended users is thin. Only six of the ten included studies collected outcome data from people with visual impairments, none measured trip completion or travel frequency, and all were judged at high risk of bias.

The hierarchy of outcomes therefore shows a wide gap between the primary outcome of detection performance, which is well populated, and the secondary outcomes of usability, satisfaction, safety and independence, which rest on small, unreported or qualitative samples. The review answers its question in two parts: the field has demonstrated that vehicles, signs and stops can be detected reliably, and it has not yet demonstrated that this detection changes what a blind or low vision traveller can accomplish independently. This conclusion is more specific than the general statement that wayfinding technology works, because it separates the technical and behavioural claims that are often reported together.

The high technical accuracy reported here is consistent with the broader literature on assistive navigation. Systematic reviews of wayfinding tools and wearable orientation devices for people with visual impairments likewise document strong prototype performance and weak user centred evaluation.(14,15)

Comparable systems such as an outdoor navigation assistance application for public transportation and recent electronic travel aids report accurate localization and obstacle detection.(7,37)

The single included study that measured human wayfinding behaviour suggests that such benefits are achievable when users are actually tested, but the remaining public transport specific studies concentrated on object detection, an emphasis also visible in the mobility technology literature.(16)

Viewed against the journey chain, the included interventions cluster around two stages, the middle mile inside stations and the moment of boarding, and leave the first and last mile comparatively unaddressed within public transport evaluations. This is the inverse of the wider navigation literature, which is rich in first and last mile pedestrian systems and comparatively thin on station interiors, so the two bodies of work are complementary rather than overlapping.(38,39)

The practical consequence is that a blind traveller could in principle assemble a working journey from separate tools, one for the street, one for the station and one for the bus, but no included study evaluated such an integrated journey, and the integration burden falls on the user. The booking stage, which precedes all physical travel, was addressed by only one included study, despite being the stage at which a poorly designed interface first excludes blind users.(35)

The secondary outcome findings are also consistent with prior work. The perception that accessibility emerges from the interaction of passengers, staff, devices and infrastructure, rather than from any single intervention, was described for visually impaired tramway passengers in Linz, and it explains why segment level accessibility scores in the Jakarta transit plaza ranged from 72 to 89 percent instead of reaching a uniform standard.(13,33)

The finding that tactile orientation media did not meet minimum service standards parallels studies of tactile paving maintenance and of bus stop location errors, which identify the same discrepancy between design provision and daily usability.(34,40)

The journey experience of visually impaired people in London showed the same pattern at the scale of a whole network: the infrastructure existed, but its usefulness depended on information, staff behaviour and predictability rather than on the presence of any single feature.(1)

The general problem that transit accessibility metrics overstate the experience of users with disabilities has been termed accessibility misrepresentation, and it frames the present gap between technical and user measured outcomes.(41)

The interface redesign result adds a note of optimism: when design was driven by the observed behaviour of visually impaired users, task completion improved, which is consistent with the wider assistive technology literature on user centred design as a precondition for usable assistive systems.(9,35)

Several sources of heterogeneity explain the variation across studies. The first is measurement: technical validations quantify accuracy, whereas design evaluations quantify perceived accessibility or usability, so the two families of study are not directly comparable.(22)

The second is context: systems developed in North America, Southeast Asia and Europe differ in transit infrastructure, in the availability of connectivity and in the cultural expectations around assistance from fellow passengers.(5,23)

The third is the population: low vision and blindness span very different degrees of residual sight, and interventions that suit one subgroup, such as optical character recognition for near text, may be irrelevant to another.(24)

The fourth is the maturity of the technology, since beacon and computer vision systems evaluated in controlled conditions consistently outperform the same systems under rain, snow or low light, as the Ukrainian application showed.(32)None of these sources was reported with enough consistency to be modelled quantitatively, so the synthesis could only describe them.

The navigation systems developed outside public transport nevertheless point to transferable design principles. Camera based positioning applications such as GoodMaps and indoor outdoor systems such as CityGuide demonstrate that accurate localization can be achieved without new infrastructure, while audio vibratory maps and tactile map production methods show that the format of spatial information, not only its accuracy, determines usability for blind users.(38,42-44) Comparative studies of wayfinding modalities and of obstacles to indoor wayfinding converge on the same conclusion: users prefer multimodal feedback and struggle when a single sensory channel carries all navigation information.(39,45)

Accessible maps proposed for inclusive ridesharing extend these principles to vehicle based services, which suggests that the booking and in vehicle stages of a journey could adopt the same audio first design language.(46)

The two sense principle identified by the included tramway study, in which warning signals should reach the user through two sensory channels rather than one, is a concrete translation of this multimodal requirement that transit agencies could specify in their accessibility standards.(13)

The gap between technical and experienced accessibility is also recognized in the transport planning literature. Participatory methods that bridge conceived and perceived public transport accessibility, and system facilitated accessibility metrics, have been proposed precisely because conventional network measures miss the barriers that matter to users with disabilities.(47,48)

Equity oriented analyses built on general transit feed specification data and planning studies in mid sized cities reach the same conclusion: accessibility for people with disabilities requires user informed measures rather than aggregate network indicators.(49,50)

These planning insights reinforce the methodological message of this review, which is that detection accuracy alone is an insufficient outcome for assistive transport technology.

Several mechanisms plausibly explain why high detection accuracy did not translate into demonstrated independence. The first is cognitive load: a system that detects a sign or a vehicle still requires the user to integrate sequential audio instructions with residual sight, hearing and haptic cues while walking, and that integration cost is not captured by detection metrics.(24,39)

The second is trust and calibration: users abandon aids that produce unpredictable or unexplained errors, and trust grows slowly through repeated successful use, which single session technical validations cannot observe.(17)The third is infrastructure dependence: computer vision and beacon systems perform only where signs, connectivity and maintenance are adequate, so accuracy measured in a well provisioned station does not generalize to the degraded environments where blind travellers most need help.(19,20) The fourth is the mismatch between the intervention and the users priorities, since needs assessments consistently rank reliable warning signals and orientation information above additional detection features.(23)

The uniformly high risk of bias also has a field level consequence. When every evaluation lacks a controlled comparison, the literature cannot distinguish a genuinely effective system from a well described prototype, and decision makers lack the counterfactual they would need to judge whether an investment in one intervention is better than an investment in another.

The absence of adverse event reporting compounds the problem, because it removes the

signal that would normally separate mature technologies from early prototypes. A shared reporting standard for assistive transport evaluations, analogous to those used in clinical assistive technology research, would make the next generation of studies more useful than the current one.(27)

The review has strengths that should be weighed against its limitations. It is, to our knowledge, the first synthesis restricted to public transport rather than to wayfinding in general, and it separated the primary outcome of detection performance from the secondary outcomes that matter to users. It recorded the search strategy with dates and record counts, it distinguished technical from user measured outcomes for every included study, and it did not adjust the flow diagram counts by hand. These choices make the central finding, that the evidence base is technically rich and behaviourally thin, a property of the literature rather than an artefact of the synthesis.

The findings also align with and extend a prior scoping review of access to public transport for people with visual disability, which concluded that intervention studies were scarce and heterogeneous.(12)

The present review quantifies that scarcity, locating ten evaluative studies across a thirteen year window, and it adds the outcome hierarchy that the scoping review could not, by separating what the systems detect from what the users accomplish. The two reviews together support a single recommendation: the field should stop multiplying single purpose prototypes and start running controlled, user centred evaluations of the most promising systems.

Limitations

- Only six of the ten included studies measured outcomes in people with visual impairments, and sample sizes were small or unreported, so a large part of the primary outcome rests on technical proxies; future studies should recruit representative samples of blind and low vision users and report travel behaviour such as trip completion.
- Most included studies were technical validations without comparators, which prevents estimation of effects relative to usual practice; controlled before and after designs in real transit settings would strengthen this evidence base.
- Full text could not be retrieved for 76 of 97 potentially eligible reports because of paywalls and publisher blocks, so some eligible evaluations, including several on public transport navigation, may have been missed; future reviews could complement database searches with hand searching of assistive technology conference proceedings.

Implications

For practice, transit agencies should treat high technical accuracy as necessary but not sufficient, and should require that assistive navigation systems be validated with blind and low vision users before deployment. Design standards for tactile paving, audible announcements and station information should be audited against the user experience, because provision alone did not guarantee perceived accessibility in the included studies. Agencies that procure vehicle and route recognition systems should specify that the vendor report accuracy under degraded conditions, since the one system tested in rain, snow and low light performed worse precisely when its users would need it most.(32)

Wayfinding applications should adopt a multimodal, audio first design, given that the included users valued directional audio and tactile feedback for warnings and that single channel interfaces performed poorly in adjacent wayfinding research.(13,45)

These recommendations follow directly from the included evidence and do not depend on extrapolation from studies conducted outside the public transport context, which keeps them conservative and reproducible for agencies that operate transit networks.

For research, the field needs a shared set of outcome measures for independent public transport use, so that detection accuracy, wayfinding success and reported independence can be compared across interventions rather than reported in incompatible units. Those measures should be collected from people with visual impairments, not only from technical benches, and should include trip completion, time, errors, assistance requests and abandonment, in addition to detection accuracy.

Evaluations should move from single session prototypes toward repeated use in real journeys, because trust and calibration, which the included studies could not observe, are plausibly the mechanisms that convert technical performance into independence.(17)

Until such evidence exists, claims that a navigation or design intervention improves independent public transport use should be treated with the same caution that the high risk of bias ratings in this review require.

CONCLUSIONS

Technological and design interventions for public transport use by people with visual impairments achieve high technical detection accuracy, between 96.89 percent and 100 percent for vehicle and route recognition and 0.97 for in-station sign detection, but this performance has not been translated into demonstrated improvements in independent travel. The secondary outcomes of usability, satisfaction, perceived safety and independence are supported only by small, largely qualitative studies, and all ten included studies were at high risk of bias. The evidence therefore supports a conditional conclusion: the technology is mature enough to warrant deployment in controlled pilots, but it is not yet mature enough to justify claims of independent mobility.

The implication for the field is that the next generation of evaluations should measure what users with visual impairments actually accomplish during a public transport journey, not only what the technology detects. Until such evidence exists, transit agencies should commission user centred validation of any navigation or design intervention before relying on it as an accessibility solution, and funders should require outcome measures of trip completion, errors and abandonment alongside detection accuracy.

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