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Beyond visual codes

Translating color through ambient haptics and passive multisensory architecture for the spatial justice of visually impaired in metro stations

Babayan Bidgoli S., Department of Architecture, Tafresh Branch, Islamic Azad University, Iran,
ORCID 0009-0007-1805-0144, sahar.babayanbidgoli@iau.ac.ir

Arabi R., Department of Architecture, Khomein Branch, Islamic Azad University, Iran,
ORCID 0009-0008-8540-7761, roozbeh.arabi@iau.ac.ir

Kalantari M., Department of Architecture, Tafresh Branch, Islamic Azad University, Iran,
ORCID 0000-0002-9696-9988, mitra.kalantari@iau.ac.ir

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Abstract

Background: Public transport environments often communicate route and safety information through visual cues, which may create barriers to independent wayfinding for people who are blind. Integrating additional sensory information into the built environment may offer a complementary approach to accessible navigation.

Objective: This study explores “Ambient Haptics” as a conceptual approach to passive, architecture-integrated guidance and examines the potential of embedded neodymium–iron–boron (NdFeB) magnetic strips to support cane-mediated navigation along a simulated pathway.

Method: An exploratory mixed-methods study was conducted in Tehran, Iran, with 32 male participants with total blindness, aged 24–45 years, all of whom had experience using a white cane. Participants completed a 20-metre simulated pathway first without magnetic guidance and then with embedded magnetic strips interacting with the metal tip of their cane. A researcher recorded travel time, unintended stops, and navigation or collision errors. Questionnaire responses and qualitative interviews were also used to examine participants’ reported mobility experiences. The trial order was fixed, and the quantitative findings are interpreted descriptively.

Results: Mean travel time decreased from 60 to 45 seconds, representing a 25% reduction. Mean unintended stops decreased from 4.5 to 1.5, and mean navigation or collision errors decreased from 3.0 to 1.0, representing reductions of approximately 66.7% in both measures. On a five-point Likert scale, reported mobility anxiety decreased from 3.8 to 2.1, sensory trust increased from 3.3 to 4.2, and perceived path control increased from 2.9 to 4.0. These findings are descriptive; participant-level data and the original statistical output were unavailable for independent reanalysis. Conclusion: The findings provide exploratory evidence that embedded magnetic guidance warrants further investigation as a passive, architecture-integrated channel for supporting cane-mediated navigation. The proposed approach may complement established accessibility provisions, but its effectiveness, durability, surface safety, and applicability in operational metro stations remain to be established through further controlled and real-world testing.

Keywords: Spatial justice, Ambient haptics, blindness, magnetic guidance, Multisensory architecture, Inclusive design.

1. Introduction

Modern public transportation systems often rely on visual information to support orientation, wayfinding, and safety communication. In complex environments such as metro stations, coloured lines, signs, and contrasting surface markings may indicate routes, passenger movement, or potential hazards. Although these visual cues can facilitate navigation for sighted passengers, their effectiveness depends on users being able to perceive and interpret the information presented. Environmental design and spatial organisation are therefore important considerations when developing accessible wayfinding strategies for people with sensory impairments (Zali et al., 2026). For people who are blind, environments that communicate essential navigational information primarily through visual cues can create substantial barriers to independent mobility. Research on navigation in complex public environments has identified independent wayfinding as an important accessibility challenge for people with visual impairments (Guerreiro et al., 2019). From the perspective of spatial justice, accessible public architecture should therefore provide meaningful navigational information through channels that do not depend exclusively on vision (Fainstein, 2014; Zali et al., 2026).

Existing approaches include wearable haptic devices, electronic mobility aids, smart canes, and smartphone-based navigation systems that use auditory or other sensory cues (Elmannai & Elleithy, 2017; Kuriakose et al., 2020; Casanova et al., 2025; Pittet et al., 2026; Skulimowski et al., 2025). These technologies can assist users, although their capabilities and practical requirements vary. Some systems require users to acquire, carry, charge, or maintain individual devices, which may introduce practical or financial barriers to access (Elmannai & Elleithy, 2017; Casanova et al., 2025). An alternative, complementary approach is to incorporate navigational information into the built environment itself, allowing architectural elements to contribute to the guidance process rather than relying exclusively on personal electronic devices.

This study explores such an approach through the concept of “Ambient Haptics”, defined here as passive, architecture-integrated tactile guidance. Its central conceptual proposition is that the navigational function conveyed by a visual colour code may be represented through a distinguishable tactile signal. This does not imply that people who are blind directly perceive the colour itself. Rather, information conventionally communicated through colour in a particular environment could potentially be recoded into tactile cues that convey equivalent navigational meaning. Research on multisensory navigation demonstrates the relevance of alternative sensory cues to wayfinding, but it does not, by itself, establish a universal correspondence between particular colours and tactile responses (Casanova et al., 2025; Skulimowski et al., 2025). Accordingly, the interpretation of any cue would depend on a clearly defined mapping between the intended information and the corresponding tactile signal, rather than on an assumption that particular colours have universal psychological meanings.

The empirical component of this study investigates a specific aspect of this proposal: the use of embedded neodymium–iron–boron (NdFeB) magnetic strips along a simulated pathway to provide a potential tactile guidance channel through interaction with the metal tip of a white cane. The study evaluates navigation performance and self-reported experiences under standard and magnetic-guidance conditions. It does not independently establish that every visual colour code can be translated into a distinct tactile response, nor does it test the system in an operational metro station. By distinguishing the conceptual model from the intervention evaluated experimentally, the study seeks to contribute to further research on passive haptic guidance and spatial justice in public architecture.

2. Background and Theoretical Framework

Improving spatial justice for people who are blind requires reconsidering how architectural information is communicated, particularly where wayfinding depends on visual information. This section reviews ocularcentrism in architectural design, the distinction between active sensory-substitution technologies and passive haptic approaches, and the proposed role of magnetic guidance in translating navigational information into tactile form. It also considers how the proposed approach relates to established tactile walking surface indicators.

2.1. Ocularcentrism and the Limits of Active Sensory Substitution

The design of public infrastructure, including metro stations, frequently gives visual information a prominent role in wayfinding and safety communication. Coloured lines, illuminated signs, and contrasting surface markings can help sighted passengers identify routes and interpret environmental information (Pallasmaa, 2012). When equivalent information is not available through other sensory channels, these design strategies may create barriers for people who cannot access the visual cues. The resulting difficulties can affect navigation, perceived independence, and mobility-related anxiety (Casanova et al. 2025; Pittet et al. 2026)

Technological sensory-substitution systems seek to make information available through an alternative sensory modality. Examples include devices that convert visual information into auditory signals and systems that provide tactile or electrotactile stimulation. Such approaches demonstrate the potential to communicate information that would otherwise be inaccessible through vision alone (Kuriakose, Shrestha, & Sandnes, 2024). However, wearable and electronic solutions may require individual equipment, power, maintenance, training, and additional expenditure. They also place much of the technological burden on the user rather than embedding all guidance functions within the physical environment (Wazirali et al. 2025).

Ambient haptics explores a complementary approach: incorporating the means of conveying information into architectural materials and components. In principle, a route or warning could be represented through distinguishable physical cues that can be accessed through contact with a cane or, where appropriate, through other forms of tactile interaction. The intended benefit is not to reproduce colour perception itself, but to make the navigational function associated with a visual code available through a non-visual channel.

The correspondence between colour-coded information and tactile signals should not, however, be assumed to be universal. Colour meanings vary according to the conventions used in a particular environment, and the relationship between a colour and a psychological response cannot be generalised to all users or settings. In addition, people with congenital and acquired blindness may have different visual experiences and learned associations. Consequently, any proposed colour-to-haptic mapping should be defined in relation to the actual wayfinding information used in the target setting and evaluated with the intended users.

2.2. Interactive Architecture and the Transition to Passive Haptics

Interactive architecture considers how the built environment can support users' activities and communicate spatial information through its configuration, material properties, and sensory cues. Rather than treating architecture solely as a static setting through which users must navigate, this perspective recognises that spatial organisation and environmental features can influence orientation and accessibility (Heylighen & Herssens, 2014; Zali et al., 2026).

Within this broader framework, passive haptic guidance uses physical cues, such as detectable surface patterns or material differences, to convey information without requiring continuous electronic actuation. Tactile walking surface indicators provide an established example of environmental features designed to support wayfinding and identify hazards (International Organization for Standardization [ISO], 2019). The magnetic-strip arrangement examined in the present study represents a proposed extension of this environmental approach: directional guidance is intended to be conveyed through the interaction between embedded magnetic strips and the metal tip of a white cane. Unlike many electronic travel aids that rely on powered devices carried or worn by users, the proposed mechanism is integrated into the pathway itself (Casanova et al., 2025; Skulimowski et al., 2025; Pittet et al., 2026). However, this distinction describes the design approach rather than demonstrating superior effectiveness. Appropriate installation, inspection, and maintenance remain necessary, and integration into the built environment does not by itself establish universal accessibility or long-term reliability.

Table 1 summarises the conceptual differences between active haptic technologies and passive, architecture-integrated guidance. These differences describe the approaches in general terms and should not be interpreted as evidence that passive systems are necessarily more effective or safer in every environment.

Table 1. Comparison of active haptic systems and passive haptic approaches in architecture

Feature	Active Haptic Systems (wearables and electronic devices)	Passive Haptic Systems (Ambient Architecture)
Power Requirement	Often requires batteries or another source of electrical power.	May use inherent material properties, such as permanent magnetic fields, without continuous electrical power for the guidance mechanism.
User requirements	May require users to acquire, carry, operate, or charge equipment.	Intended to reduce reliance on user-owned electronic guidance equipment.
Maintenance	May require hardware repairs, charging, or software maintenance.	Requires inspection and maintenance of the integrated materials and finished surfaces.
Relationship with architecture	Guidance is commonly delivered through a separate device.	Guidance components are incorporated into the built environment.
Potential feedback mechanisms	Electronic vibration, electrotactile stimulation, and auditory cues.	Physical cues such as surface texture or magnetic interaction through a suitable cane tip.
Accessibility considerations	Access may depend on device availability, affordability, usability, and training.	May reduce the need for personal equipment, but accessibility and safety must be evaluated for the intended users and environment.

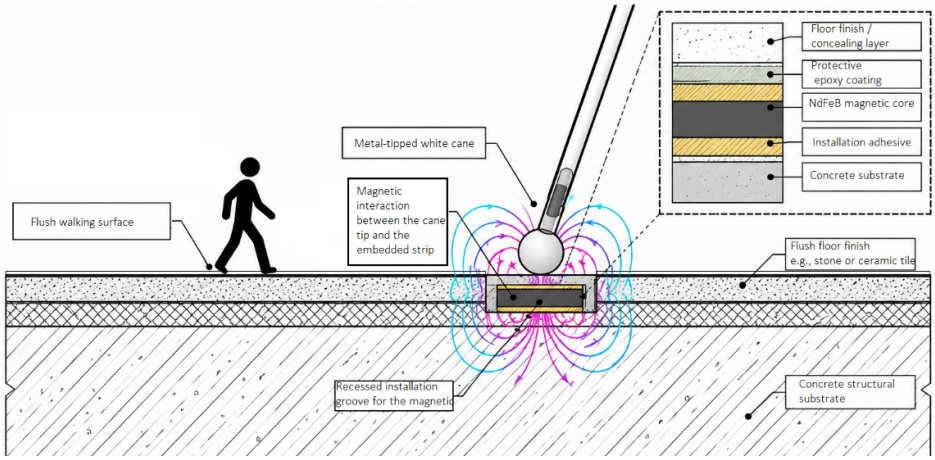
Passive haptic guidance should also be considered in relation to tactile walking surface indicators (TWSIs), including raised guiding patterns and truncated-dome warning surfaces. ISO 23599:2019 identifies guiding patterns and attention patterns as established forms of tactile walking surface indicators intended to support the safe and independent mobility of blind or vision-impaired people (International Organization for Standardization [ISO], 2019). Unlike these surface indicators, the magnetic concept examined here is intended to provide route information through magnetic interaction with a cane tip while keeping the walking surface visually continuous. The two approaches serve related but not identical functions: magnetic guidance may be investigated as a complement to established tactile indicators, not as a replacement for required warning surfaces or other accessibility provisions. Any proposed installation would need to meet applicable accessibility and safety requirements and be assessed for detectability, durability, and surface slip resistance.

The present study therefore examines a specific passive haptic intervention within a controlled simulated pathway. Broader claims about performance in crowded or noisy metro stations require further evaluation under operational conditions (Plikynas et al., 2020).

2.3. Neodymium Magnetic Guidance as a Sensory Translator

A key requirement for translating navigational information into a tactile form is that the resulting signals should be sufficiently distinguishable to convey the intended meaning. This study considers neodymium–iron–boron (NdFeB) magnetic strips as a means of providing pathway guidance through a passive physical interaction. Figure 1 illustrates the proposed integration of magnetic strips beneath the architectural floor finish.

Figure 1. Proposed integration of a neodymium magnetic strip beneath an architectural floor surface for cane-mediated guidance.



Note. The figure illustrates the proposed placement of an NdFeB strip beneath a protective floor finish. The system is intended to provide a potential tactile guidance channel through interaction with the metal tip of a white cane while maintaining a continuous floor surface. The use of an epoxy or other protective coating does not, by itself, establish adequate slip resistance, accessibility, or long-term durability; these properties require separate material and installation testing.

NdFeB is a permanent-magnet material known for its high magnetic energy density (Sagawa et al., 1984). In the proposed installation, magnetic strips are concealed beneath the floor surface and aligned with the intended route. The experimental arrangement used white canes with metal tips; no permanent magnet was attached to the cane. The effectiveness of the physical interaction depends on the magnetic properties of the tip and the installed configuration and should be evaluated for the materials used. The proposed arrangement is intended to provide tactile information through the cane without requiring electronic signal processing or continuous electrical power for the permanent-magnet guidance mechanism.

Table 2. Selected characteristics of neodymium (NdFeB) and standard permanent magnets for potential architectural integration.

Characteristic	Neodymium (NdFeB) Magnets	Standard Magnets (Ferrite / Alnico)
Magnetic Strength (Energy Density)	High magnetic energy density, potentially suitable for compact installations.	Magnetic performance varies by material and grade; larger dimensions or a different configuration may be needed for a comparable field.
Spatial Footprint	Can provide a relatively strong magnetic field in a compact component.	Required size depends on the selected material and the intended field strength.
Corrosion Resistance	Susceptible to corrosion in some environments; protection may be required depending on the grade and installation.	Corrosion resistance varies by material and grade.
Thermal Stability	Magnetic properties vary with temperature and magnet grade; performance under the intended environmental conditions must be verified.	Thermal behaviour also varies by material and grade.
Mechanical Durability	The material can be brittle and may require protection against damage during installation and service.	Mechanical durability varies by material and component design.
Cost and Implementation	Material and installation costs depend on grade, dimensions, floor construction, and protective measures.	Costs and installation requirements depend on the selected material and the performance needed.

Selected characteristics of NdFeB and standard permanent magnets are summarised in Table 2. Within the conceptual model, the function of colour-coded navigation is translated into differentiated tactile information rather than into the perception of colour itself. For example, where a particular wayfinding system uses a continuous coloured line to identify a route and a contrasting colour to indicate a warning, the associated functions could, in principle, be represented by different tactile signals. A continuous tactile cue might identify route continuity, while a distinct warning cue might indicate a decision point or hazard. Such signals would need to be specified and tested to ensure that users can distinguish them reliably.

The “Blue Line” and “Yellow Line” examples sometimes used to describe route flow and hazard warning are therefore illustrative of a possible mapping, not universal psychological rules. Blue does not inherently produce a reassuring response in every person or culture, nor does yellow necessarily trigger the same level of alertness in all settings. The proposed translation concerns the navigational meaning assigned to these colours by a specific environmental convention. The tactile alternatives must communicate that meaning through distinguishable and consistently applied cues, rather than relying on presumed universal colour–emotion associations.

The empirical component of the present study assessed a continuous magnetic-guidance pathway and compared navigation with and without the magnetic strips. It did not independently compare multiple colour-specific tactile codes or establish that participants could identify separate “blue” and “yellow” meanings through different haptic signals. The results should consequently be interpreted in relation to the navigation task that was tested, while the broader

translation of multiple visual codes into differentiated tactile patterns remains a topic for further experimental investigation.

Protective measures may be necessary to limit the environmental degradation of embedded magnets, particularly where moisture or repeated mechanical loading is present (Dobzhanskyi, 2022). However, protective coatings, low energy requirements, or a compact installation should not be taken as proof of long-term reliability, slip safety, or suitability for every public environment. These factors require verification as part of future material testing and field evaluation.

3. Methodology

This study adopted an applied, exploratory experimental design using a mixed-methods approach combining quantitative and qualitative data. It investigated whether passive magnetic haptic guidance integrated into an architectural pathway could support the navigation performance and perceived mobility comfort of people with total blindness. The intervention was designed as a low-cost, infrastructure-integrated approach that could potentially complement existing accessibility measures in public spaces. The experimental findings are interpreted in relation to the simulated pathway used in this study and are not assumed to demonstrate effectiveness in operational metro stations.

3.1. Research Design and Participants

The study included 32 male participants with total blindness, aged 24–45 years, who were purposively recruited through an association for blind people in Tehran, Iran. All participants had experience using a white cane. The distribution of participants with congenital and acquired blindness, the duration of visual impairment, the extent of mobility training, and the presence of additional mobility-related conditions were not documented in the available study records. These characteristics therefore cannot be reported or compared in the present analysis.

Each participant completed both experimental conditions: a standard pathway without magnetic guidance and the same pathway equipped with magnetic guidance. The standard condition was always completed first, followed by the magnetic-guidance condition. This within-participant design enabled comparison of the recorded navigation measures and questionnaire responses between conditions. However, because the order was not counterbalanced, practice and order effects cannot be ruled out.

The sample was selected purposively according to the study's participant criteria and access to the target population. No a priori sample-size calculation or statistical power analysis was conducted for the quantitative component. Theoretical saturation was considered in relation to the qualitative interviews only and was not used as a justification for quantitative sample adequacy. Accordingly, the quantitative findings should be interpreted as exploratory rather than as definitive evidence of effectiveness across the wider population of people with total blindness.

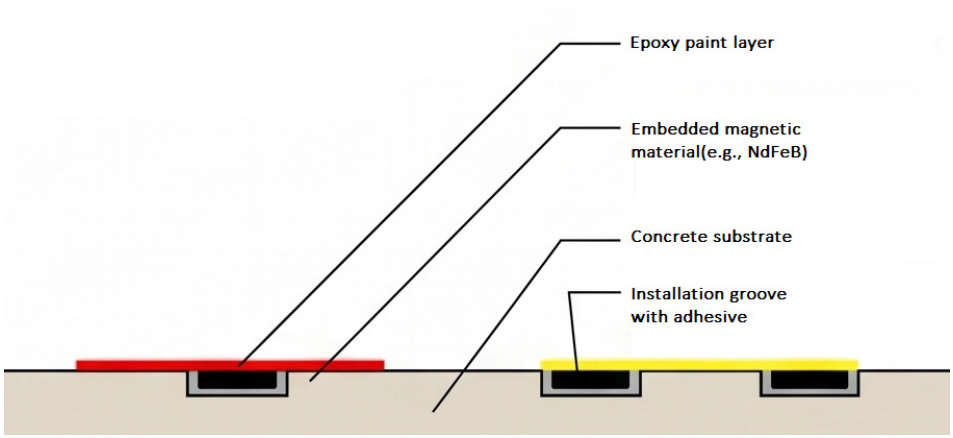
3.2. The Simulated Environment and Intervention

The experiment was conducted on a 20-metre simulated architectural pathway. Although the intervention was developed with potential applications in public environments such as metro stations in mind, the experimental pathway was not an operational metro station or a healthcare facility. It was a controlled route used to compare navigation with and without magnetic guidance.

Neodymium–iron–boron (NdFeB) magnetic strips were installed continuously beneath the designated route, aligned with the coloured directional lines used as visual guidance for sighted users. Participants navigated the pathway using their usual white canes with metal tips; no permanent magnet was attached to the cane. In the magnetic-guidance condition, interaction between the metal cane tip and the embedded magnetic strips was intended to provide tactile feedback through the cane, helping participants detect the pathway's direction and continuity.

Each participant first completed the route without magnetic guidance. Travel time, unintended stops, and navigation or collision errors were recorded by a researcher through direct observation. After a rest interval of approximately five minutes, the participant completed the same route with magnetic guidance, and the same performance measures were recorded. The questionnaire was administered separately after each condition: first after the standard route and then after the magnetic-guidance route. Semi-structured interviews were conducted after the trials to explore participants' experiences and perceptions of the guidance system. The fixed order of the trials is a limitation because possible practice effects cannot be separated from the effects of the intervention. Figure 2 illustrates the schematic cross-section of the embedded magnetic guidance strip.

Figure 2. Schematic cross-section of the embedded magnetic guidance strip.



Note. The schematic illustrates the proposed integration of NdFeB magnetic strips beneath a protective floor finish. The strips are intended to preserve the visible colour-coded route for sighted pedestrians while providing a potential tactile guidance channel through contact between the magnetic field and the metal tip of a white cane. The diagram represents the proposed construction arrangement and should not be interpreted as evidence of long-term durability or slip safety.

3.3. Data Collection and Analysis

Data collection combined direct observation of navigation performance, questionnaire responses, and qualitative interviews.

- Objective measures. The researcher manually recorded the time required to traverse the 20-metre pathway, the number of unintended stops, and the number of navigation or collision errors under each condition. These measures were based on direct observation rather than electronic motion tracking.
- Questionnaire measures. Participants completed a 20-item Persian questionnaire addressing spatial perception and mobility-related experiences. The questionnaire was informed by Loomis et al. (2001) and used a five-point Likert response scale ranging from 1 (strongly disagree) to 5 (strongly agree). The researcher read the items aloud in Persian and recorded participants' responses. The same questionnaire was administered after each route

condition, allowing comparison of self-reported outcomes between the standard and magnetic-guidance conditions.

The dimensions and Cronbach's alpha values reported in the original questionnaire table are presented in Table 3. These reliability coefficients are reproduced from the available records and could not be independently recalculated because the participant-level dataset and original statistical output were unavailable.

- Qualitative data. Interview notes were documented and coded manually to identify recurring experiences concerning route navigation, tactile feedback, perceived security, and path control. Theoretical saturation was judged in relation to the qualitative material. A separate quantitative sample-size justification was not inferred from this process.

The original manuscript reports that quantitative data were analysed using IBM SPSS Statistics, version 26, using descriptive statistics and mean-comparison procedures. However, the participant-level dataset and original SPSS output are no longer available. The analyses could therefore not be independently rerun, and the exact statistical procedures, assumptions, and inferential results could not be re-examined during this revision. The retained numerical results are consequently presented descriptively. Test statistics, degrees of freedom, exact p-values, standard deviations, confidence intervals, and effect sizes cannot be reconstructed reliably from the available summary values alone. Inferential claims that cannot be verified from the retained records are therefore not presented as independently confirmed results.

Table 3. Dimensions of the spatial perception and mobility questionnaire and reported internal consistency.

Questionnaire Dimension	Number of Items	Cronbach's Alpha (α)
Spatial Perception	3	0.78
Wayfinding	3	0.81
Path Control	3	0.74
Mobility Anxiety	3	0.85
Sensory Trust	3	0.80
Interactive Architecture /	3	0.82
Haptics technology	2	0.76
Total Questionnaire	20	0.89

4. Results and Discussion

The recorded observations and retained questionnaire summaries suggest differences between the standard pathway and the magnetic-guidance condition. Because the participant-level data and original statistical output are unavailable, the findings are presented descriptively and should be interpreted as exploratory evidence from a controlled, simulated route.

4.1. Objective mobility performance

The original results table reports a mean travel time of 60 seconds for the standard pathway and 45 seconds for the magnetic-guidance pathway. This corresponds to a descriptive reduction of 25%. The reported mean number of unintended stops decreased from 4.5 to 1.5, while the mean number of navigation or collision errors decreased from 3.0 to 1.0. Both changes correspond to reductions of approximately 66.7%.

These figures are descriptive comparisons of the values retained in the original tables. They do not, by themselves, establish statistical significance or demonstrate that the same reductions would occur in an operational metro station. The fixed order of the trials also means that the contribution of practice or route familiarity cannot be ruled out. The descriptive comparisons of these objective mobility measures are presented in Table 4.

Table 4. Descriptive comparison of objective mobility measures between the standard and magnetic-guidance pathways.

Mobility measure	Standard pathway (reported mean)	Magnetic-guidance pathway (reported mean)	Descriptive change
Travel time over 20 metres	60 seconds	45 seconds	25 % reduction
Unintended Stops	4.5 instances	1.5 instances	Approximately 66.7% reduction
Navigation/Collision Errors	3.0 instances	1.0 instance	Approximately 66.7% reduction

Note. Percentage changes were calculated from the means reported in the original table. The original participant-level records were unavailable for independent verification. No independently verified inferential statistics are reported.

4.2. Psychological outcomes and spatial perception

The retained questionnaire summaries indicate lower reported mobility anxiety and higher reported sensory trust and path control after the magnetic-guidance condition than after the standard pathway. Mobility anxiety decreased from a reported mean of 3.8 to 2.1, sensory trust increased from 3.3 to 4.2, and path control increased from 2.9 to 4.0 on the five-point Likert scale.

These changes are presented as descriptive differences between the two conditions. In the absence of participant-level responses and the original statistical output, their statistical significance and variability cannot be independently established. The reported percentage changes are based on the original means and should not be interpreted as independently verified estimates of treatment effect.

The qualitative interview notes described participants' experiences of the tactile guidance and their perceptions of route navigation. Such accounts may help contextualise the numerical summaries, but they do not establish that the system will produce the same outcomes in unfamiliar, crowded, or operational environments. The reported mean scores for these psychological and spatial-perception dimensions are summarised in Table 5.

Table 4. Reported mean scores for selected psychological and spatial-perception dimensions.

Psychological Dimension	Pre-test / Standard Path	Post-test / Magnetic Path	Percentage Change
Mobility Anxiety	3.8	2.1	Approximately 44.7% decrease
Sensory Trust	3.3	4.2	Approximately 27.3% increase
Path Control & Independence	2.9	4.0	Approximately 37.9% increase

Note. Scores use a five-point Likert scale. Percentage changes are calculated from the retained means and are descriptive only. The original participant-level responses were not available for reanalysis.

4.3. Technical limitations and implications for spatial justice

A passive tactile channel is introduced, which can be accessed using a white cane. Its potential accessibility benefit is that route information may be conveyed through the built environment rather than relying exclusively on visual signs or powered devices carried by users. However, the present experiment evaluated a 20-metre simulated pathway under controlled conditions; it did not test the system in an operational metro station or under sustained passenger traffic.

Several technical and practical issues require further investigation before real-world implementation. First, the magnetic properties of NdFeB materials vary with temperature and depend on the magnet grade and operating conditions (Constantinides & Gulick, 2004; Arnold Magnetic Technologies, n.d.). Manufacturer technical information reports a reversible temperature coefficient of remanent induction of approximately −0.12% per °C for representative NdFeB grades, while the temperature coefficient of intrinsic coercivity is a different material parameter (Arnold Magnetic Technologies, n.d.). These coefficients should not be interpreted as direct measurements of the guidance system's sensitivity. Accordingly, the previously stated 15% reduction in guidance sensitivity above 40°C should not be presented as an established result: it was not measured in the present study, and the available material-level data do not establish a 15% reduction in the performance of the complete installed system. The actual effect of temperature on cane-mediated feedback must be evaluated for the selected magnet grade and the complete installed assembly.

Second, long-term performance may be affected by the durability of the floor finish, moisture exposure, corrosion protection, repeated mechanical loading, and wear caused by pedestrian traffic. NdFeB magnets can be susceptible to corrosion, and protective coatings may be required depending on the magnet grade and environmental conditions (Arnold Magnetic Technologies, n.d.; Primc & Mozetič, 2024). The integrity of the protective epoxy layer and the condition of the finished surface would therefore require periodic inspection. Any raised edges, cracking, delamination, or changes in surface friction could create hazards for cane users and other pedestrians. Slip resistance and the safety of the finished surface must be assessed independently using appropriate test methods; the presence of a protective coating alone does not establish that the pathway is safe (European Committee for Standardization [CEN], 2021).

Third, the simulated route did not reproduce the full complexity of an operational metro station, including crowding, competing pedestrian flows, platform-edge hazards, background vibration, or the effects of prolonged use. The results should not be generalised to these conditions without further testing. Future research should examine different environmental temperatures, humidity conditions, surface wear, crowding, route configurations, and user characteristics, including differences in the onset of blindness and experience with mobility aids. A counterbalanced trial order, a larger and more fully characterised sample, and a prospective sample-size calculation for a defined primary outcome would strengthen subsequent evaluations.

Finally, magnetic guidance should be considered in relation to established tactile ground surface indicators, including guiding patterns and attention patterns, rather than as a demonstrated replacement for them. ISO 23599:2019 provides specifications and installation recommendations for tactile walking surface indicators intended to support the mobility of people who are blind or have low vision (International Organization for Standardization [ISO], 2019). The potential role of magnetic guidance is to complement existing accessibility provisions by conveying route continuity through interaction between a white cane's metal tip and embedded magnetic strips. Compatibility with applicable accessibility requirements, tactile paving, floor-surface safety, and emergency wayfinding would need to be assessed before implementation.

Within these limitations, the study provides exploratory evidence that a continuous, embedded magnetic pathway warrants further investigation as a passive architectural approach to accessible navigation. The findings support further controlled and real-world testing, rather than a definitive claim of effectiveness, long-term durability, or universal applicability.

5. Conclusion

This study investigated the potential of passive magnetic haptic guidance to support accessible navigation for people with total blindness. Through the concept of "Ambient Haptics", it explored how magnetic elements embedded within an architectural pathway could provide route information through tactile feedback transmitted via a white cane. The approach aims to incorporate an additional channel of navigational information into the built environment, potentially complementing existing accessibility measures without requiring users to carry powered electronic guidance devices.

The experimental evaluation involved 32 male participants with total blindness, aged 24–45 years, all of whom had experience using a white cane. Participants completed a 20-metre simulated pathway first without magnetic guidance and then with magnetic guidance. The values retained in the original results tables indicated a reduction in mean travel time from 60 to 45 seconds (25%), unintended stops from 4.5 to 1.5 (approximately 66.7%), and navigation or collision errors from 3.0 to 1.0 (approximately 66.7%). The reported questionnaire means also indicated a decrease in mobility anxiety from 3.8 to 2.1 and increases in sensory trust from 3.3 to 4.2 and path control from 2.9 to 4.0 on a five-point Likert scale.

These findings should be interpreted as exploratory descriptive evidence. The original participant-level dataset and SPSS output were unavailable for independent reanalysis; therefore, the statistical significance and variability of the reported differences could not be verified during this revision. Furthermore, all participants completed the conditions in the same order, so potential practice and order effects cannot be excluded. The findings do not establish the effectiveness of the system in operational metro stations or other complex public environments.

The proposed approach has potential as a passive, infrastructure-integrated complement to existing accessibility measures. However, practical implementation would require further evaluation of magnetic performance under relevant temperature and humidity conditions, durability under repeated pedestrian loading, the integrity of the protective floor finish, and the slip resistance and overall safety of the finished surface. The effects of environmental conditions on the complete installed system should be measured directly rather than inferred solely from the temperature coefficients of the magnetic material.

Future research should include larger and more fully characterised participant samples, prospective sample-size calculations based on defined primary outcomes, counterbalanced experimental conditions, and trials in operational environments. Further investigation should also examine how magnetic guidance can complement established tactile ground surface indicators and other accessibility provisions. Differences in users' mobility-training backgrounds and histories of blindness should also be considered in subsequent evaluations.

In conclusion, this study provides preliminary evidence that embedded magnetic strips warrant further investigation as a passive means of conveying route information through the built environment. Although the findings do not establish effectiveness across all settings, they identify a potential direction for more inclusive architectural wayfinding and support further evaluation of infrastructure-based haptic guidance as one component of accessible public-space design.

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Conflict of Interest. The authors declare that there is no conflict of interest regarding the publication of this article.

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