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Impact of Hearing Impairment on Independent Travel in Individuals With Normal Vision, Low Vision, and Blindness

Philip Reed[1,2], Joseph Paul Nemargut[3], Judith E. Goldstein[1], Coral E. Dirks[4] and Yingzi Xiong[1,5]

Abstract

Individuals with dual sensory impairment (DSI) often have reduced independence in their daily activities. Vision impairment is consistently reported to play a more dominant role than hearing impairment on home-based daily living, while little is known regarding the relative impact of vision and hearing impairments on tasks such as independent travel that require interacting with more complex environments. To address this knowledge gap, we administered a semistructured survey in a convenience sample of 161 individuals with normal vision, low vision, or blindness, with or without hearing impairment. A combination of qualitative and quantitative approaches was used to analyze the data. Compared to normal vision, low vision and blind participants were significantly less likely to be frequent travelers. Low vision participants reported that vision impairment had a greater impact than hearing impairment on their travel independence, while blind participants reported hearing impairment to have a greater impact than blindness on their travel independence. The unique challenges in blind individuals were highlighted by their concerns on localizing dynamic sounds such as traffic during travel. Seventy percent of the hearing-impaired participants wore hearing aids and reported high utility for speech perception, but there was a significant reduction in the utility of hearing aids for sound localization especially for the blind participants. Our results reveal the interaction between vision and hearing impairments on independent travel and emphasize the need for an integrated rehabilitation approach for this population.

Keywords

hearing impairment, vision impairment, independent travel, hearing aids, sound localization

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Introduction

The number of individuals with co-occurring vision and hearing impairment, or dual sensory impairment (DSI), is increasing. The prevalence of DSI was estimated to approach 18% for individuals 50 years or older (Bright et al., 2023), and 40% of patients seeking vision rehabilitation also reported hearing impairment (Goldstein et al., 2012). DSI may lead to difficulty with social and functional activities, posing unique challenges in the rehabilitation for individuals affected (Capella-McDonnall, 2005; Chia et al., 2006; Crews & Campbell, 2004; Saunders & Echt, 2017; Xiong et al., 2024). Current rehabilitation efforts explore treatment strategies for hearing and vision impairments separately, yet the intersection of these conditions remains relatively unexplored.

Existing research on the impact of DSI on functional independence, including activities of home-based activity of daily living (ADL), often report a primary effect of vision impairment, with little additional contribution of hearing impairment (Brennan et al., 2005; Keller et al., 1999; Lin et al., 2004). However, the impact of hearing impairment on individuals with DSI may be underestimated due to the reliance on

[1]Lions Vision Research and Rehabilitation Center, Wilmer Eye Institute, Johns Hopkins University, Baltimore, MD, USA
[2]Department of Medicine, Science, and the Humanities, Johns Hopkins University, Baltimore, MD, USA
[3]School of Optometry, Université de Montréal, Montréal (Qc), Canada
[4]Department of Communication Sciences & Disorders, University of South Dakota, Vermillion, SD, USA
[5]Department of Psychology, University of Minnesota, Minneapolis, MN, USA

Corresponding author:
Yingzi Xiong, Lions Vision Research and Rehabilitation Center, Wilmer Eye Institute, Johns Hopkins University, Baltimore, MD 21287, USA.
Email: yxiong36@jhu.edu

vision during home-based ADL tasks such as cooking, cleaning, and self-hygiene. Tasks outside of home environments, such as independent travel, remain important for older individuals (Mueller-Schotte et al., 2019) but were less explored in the context of DSI. Travel-related tasks require a different skill set with more complex interactions with the environment, which may show a more prominent role of hearing impairment. Further, prior studies on DSI and independence were predominantly population-based and included individuals with mild or moderate vision impairment, which may limit the generalization of findings to individuals with more severe vision loss and blindness. To fill these knowledge gaps, the current study investigated the impact of concurrent hearing and vision impairment on independent travel in individuals with vision status ranging from normal vision, low vision, to total blindness.

Spatial localization is a fundamental skill during independent travel. Spatial localization refers to judging the direction and distance of objects in relation to oneself, which is a critical aspect of spatial awareness that enables individuals to navigate their surroundings safely and effectively. Much research on spatial localization has been devoted to people with normal vision and normal hearing. It is well-known that vision is usually more precise and accurate than hearing in spatial localization. When there is a conflict between vision and hearing spatial cues, vision tends to dominate the spatial perception (Ahrens et al., 2019; King, 2009; Sheffield et al., 2023). In complex situations where there are multiple sound sources (e.g., traffic or speech), the addition of visual spatial cues improves sound source localization and speech perception (Bernstein & Grant, 2009; Durlach et al., 1981; Xiong et al., 2023; Yuan et al., 2021; Zheng et al., 2022).

For individuals with visual impairment, the impaired visual localization makes their reliance on sound cues for localization more prominent (Legge & Chung, 2016; Xiong et al., 2023; 2024). These spatial hearing skills are particularly important for individuals with severe vision impairment and total blindness. Hence, there is an emphasis on the awareness and accurate localization of sound during Orientation & Mobility (O&M) training, a rehabilitation intervention provided to individuals with vision impairment and blindness (Long & Giudice, 2010). During conventional O&M training, specialists engage with patients in real-world environments such as street intersections and train the patients to attend to the auditory information in the environment and fine-tune their spatial hearing skills. However, neither guidelines nor consensus statements exist for addressing the sound localization challenges faced by individuals who have concurrent vision and hearing impairments (Brabyn et al., 2007; Simon & Levitt, 2007). As the prevalence of DSI increases, vision rehabilitation specialists are also increasingly recognizing the importance of addressing spatial hearing challenges faced by their patients with hearing impairment.

Hearing loss interferes with the essential auditory cues required for sound localization, such as interaural level differences (ILDs) and interaural time differences (ITDs), a challenge further exacerbated by hearing aids. The physical presence of a hearing aid alters the natural shape of the ear, reducing the effectiveness of pinna-related spectral cues. This is especially problematic for differentiating sounds originating from the front versus the back, leading to front-back confusions (e.g., judging whether an incoming traffic sound is from the front or back) (Carette et al., 2014). Furthermore, the amplification process in hearing aids often compresses sounds, which distorts ILDs and diminishes their reliability as localization cues. For example, loud sounds may be amplified less than quiet sounds, effectively reducing the natural intensity differences that help localize sound sources. ITDs may also be affected if the hearing aid introduces processing delays that disrupt the timing cues between the ears. However, restoring spatial hearing ability is secondary to optimizing speech perception through hearing aids (Arlinger, 2003; Dalton et al., 2003; Lin et al., 2013, 2023; Mener et al., 2013; National Academics of Sciences, Engineering and Medicine, 2016; Strawbridge et al., 2000). For people with hearing loss and normal vision, spatial hearing deficits are less problematic because vision can largely compensate for them (Brabyn et al., 2007; Simon & Levitt, 2007). Only recently have researchers and manufacturers started devoting their attention to enhancing spatial hearing cues (Sockalingam et al., 2009; Wiggins & Seeber, 2013), but still few devices prioritize preserving spatial cues.

Far less is known about the effect of hearing loss and hearing aids in people with dual sensory impairment. To meet these knowledge gaps, we conducted a semistructured survey in participants with normal vision, low vision, and near-total or total blindness (i.e., without form vision), with or without hearing impairment. All groups were asked to report their travel frequency and the perceived impact of vision and/or hearing on their travel independence. Participants with hearing impairment were further asked to report the use of hearing aids, the utility of hearing aids for speech perception and sound localization, and tasks in everyday life that they found difficult to localize objects by sound. We hypothesized that individuals with vision impairment, especially those who are blind, would perceive more challenges with sound localization and are more likely to reduce independent travel due to their hearing impairment. Insights from this research will contribute to the development of targeted multidisciplinary interventions and support systems for independent travel by people with DSI.

Methods

Participants

One hundred sixty-one participants were recruited from the Retiree Volunteer Center at the University of Minnesota, the Minnesota Laboratory for Low Vision Research, the Vision Loss Resources of Twin Cities, and the Envision

Low Vision Rehabilitation Center. Individuals were eligible for the study if they were aged 18 years or older and had normal hearing or self-reported hearing impairment, however totally deaf candidates were excluded. The inclusion criteria for vision status were broad, ranging from normal vision to total blindness without form vision. Participants who had cognitive impairment that may affect their spatial abilities were excluded from study.

This study was approved by the University of Minnesota Institutional Review Board (STUDY00001360) and followed the Declaration of Helsinki. Verbal consent was acquired from each participant prior to their participation.

Semi-Structured Survey

A semi-structured survey was conducted using Qualtrics (an online survey tool, Qualtrics, Provo, UT) and administered through Zoom videoconferencing or a phone call according to participants' preference. The survey was designed to include general questions regarding individual health, rehabilitation history, and travel habits. Survey questions were read aloud by a researcher and the participants answered each question verbally. If a participant could not understand a question, the researcher repeated or rephrased the question and provided clarification. Real-time transcriptions were provided by Zoom, and American Sign Language service was available to accommodate participants' needs.

During the survey, all participants were queried regarding their age, gender, vision/hearing status, physical conditions that may affect mobility, and travel characteristics. Normal cognitive status was confirmed by the Mini Mental State Exam for the Visually Impaired (MMSE-Blind, Busse et al., 2002). Because standard screening using letter charts or audiometers were only feasible for a portion of the participants due to travel or geographic restrictions (available data were summarized in Supplemental Appendix 1), participants were categorized to different vision and hearing groups based on their self-reported vision and hearing status. Specifically, participants were categorized as normal vision if they reported "no" to the question "Do you have vision problems that cannot be corrected by glasses or contact lenses." Participants were categorized as blind if they describe their vision as "counting fingers," "hand waving," "light perception," or "no light perception." The remainder of the participants was categorized as low vision. Similarly, participants were characterized as normal hearing if they answered "no" to the question "Do you have a hearing impairment?," and otherwise impaired hearing. Questions regarding travel characteristics included travel frequency during a typical week and places visited most often.

Participants identified with vision and/or hearing impairment were further asked questions regarding their diagnosis, onset of impairment, and history of vision and hearing rehabilitation (e.g., participation in Orientation & Mobility training, use of hearing aids, etc.). While all participants answered questions related to travel regardless of their vision and hearing status, those with vision and/or hearing impairment were asked to articulate whether their travel independence was limited by their vision and/or hearing impairment.

Due to our interest in sound localization, participants with hearing impairment were instructed to describe up to five situations in their daily experiences that posed the most significant challenges for localizing objects through sound. The working definition of spatial localization was clearly described to the participants as "*determining the direction and distance of objects in relation to ourselves.*" Researchers conducting the survey manually recorded the participants' responses in the Qualtrics text entries. When participants could not provide all five situations, the researchers repeated the definition of spatial localization and encouraged the participants to think about their everyday activities, until the participant confirmed that they could not provide more scenarios. Hearing aid users were further queried about the perceived helpfulness of hearing aids for speech perception and sound localization.

A complete list of questions asked is provided in Supplemental Appendix 2. Average survey administration time was 40 min ranging from 25 to 55 min. All 161 participants were able to proceed to the end of the survey.

Data Analysis

Data analyses were performed using the R software (R Core Team, 2005, Version 2021.09.2, build 382). Descriptive statistics were used to summarize participant demographics, vision and hearing status, mobility limitations, travel habits, O&M training received, and use of hearing aids, etc. ANOVA test ("aov" in "stats" package here and below, if not specified) was used to compare group differences in continuous variables such as age and onset. When the normal distribution of the continuous variable was not met in a Shapiro-Wilk test ("shapiro.test"), a Kruskal-Wallis test ("Kruskal.test") was conducted. When a significant main effect of the group was found, pairwise comparisons were conducted with Bonferroni corrections. Chi-squared test ("chisq.test") was used to compare group differences in categorical variables such as travel frequency and hearing aids usage. When any category had fewer than five samples, a Fisher's exact test ("fisher.test") was conducted instead.

Logistic regressions were constructed to explore the contributions of age, gender, vision status, hearing status, physical status, and O&M history on travel limitations ("yes" or "no" to limitations due to vision or hearing loss), using generalized linear model with "binomial" family and "logit" link ("glm"). All dependent variables in the glm models were confirmed to be binary prior to the glm analyses. ANOVA ("Anova" in "Car" package) was used to examine the significance of each parameter, and pseudo-R^2 ["lrm" function in "rms" package (Harrell, 2025)] was used to report how well the model fit the data.

Thematic analysis was manually conducted to identify recurring patterns across all participants in self-reported sound localization difficulties (Clarke & Braun, 2013). Themes of interest were generated from participants' responses and interpretations by the team's Orientation & Mobility training expertise (JPN), audiology expertise (CED), and research expertise on spatial hearing (YX and CED). Three themes were thus identified, including type of sound (e.g., traffic, speech, and electronics), context of scenario (e.g., travel, residential, and social), and cause of difficulty (e.g., dynamic sound, reverberation, and volume). Two raters (PR and YX) first completed independent categorizations for each participant's response without any restrictions of possible categories. For example, a patient description of "I have a hard time locating traffic if walking on sidewalk" was labeled as traffic sound (type of sounds), travel (context of scenario), and dynamic sound (cause of difficulty). Based on comparing PR and YX's categorizations, categories with similar contents but different names were unified, and categories with discrepancies were noted. A third rater (JPN) then completed a third categorization to resolve discrepancies between the first two raters. The frequency of each category for each theme in the final categories was then summarized for each group. In computing the number of participant reporting each category, a participant was only counted once if they provided multiple scenarios related to one category.

Results

Participant Characteristics

Among the 161 participants (99 females), 51 were categorized as normal vision, 56 as low vision, and 54 as blind (Table 1). For the blind and low vision groups, the self-reported causes of vision loss were primarily macular degeneration (14%), glaucoma (12%), retinitis pigmentosa (11%), and retinopathy of prematurity (9%). Participants' age ranged from 19 to 89 years, with a median age of 66 years. There was a significant age difference across the three groups [$\chi^2(2) = 7.09$, $p = .029$] and posthoc analysis showed that the normal vision group was slightly older than the blind group (mean age = 53 years vs. 51 years, $z = 2.44$, $p = .044$). Compared to the low vision group, the blind group had significantly earlier onset of vision loss [averaging 8.7 years vs. 34.5 years, $\chi^2(1) = 18.06$, $p < .001$].

The frequencies of self-reported hearing impairment were similar across the normal vision ($N = 23$, 45%), low vision ($N = 22$, 39%), and blind ($N = 28$, 52%) groups. The self-reported cause of hearing impairment was primarily late onset sensorineural hearing loss and there was no significant group difference in the onset across the three groups [$\chi^2(2) = 4.74$, $p = .093$].

The frequencies of other self-reported physical conditions that affect mobility were also similar across the normal vision ($N = 16$, 31%), low vision ($N = 17$, 30%), and blind ($N = 19$, 35%) groups [$\chi^2(2) = 0.32$, $p = .85$]. Nighty-four percent ($N = 51$) of the blind participants have received O&M training, while 45% ($N = 25$) of the low vision participants have received O&M training [$\chi^2(1) = 29.64$, $p < .001$].

Travel Frequency and Travel Independence

Figure 1 characterizes the self-reported travel characteristics across groups. Participants were categorized as "frequent traveler" if they reported going out at least 3 times per week, and otherwise categorized as "infrequent traveler." While all participants ($N = 51$, 100%) in the normal vision groups were frequent travelers regardless of their hearing status, fewer participants in the low vision ($N = 48$, 85%, $p = .006$ by Fisher's exact test) and blind groups ($N = 41$, 76%, $p < .001$ by Fisher's exact test) self-reported as frequent travelers (Figure 1A). In univariate logistic regressions with age, gender, vision status category (normal vision, low vision, and blindness), hearing status category (normal hearing and hearing impairment), mobility limitations (yes and no), and history of O&M training (yes and no) as independent variables, we found that the vision status category was the only significant predictor for an individual being an infrequent traveler [$\chi^2(2) = 17.93$, $p < .001$, pseudo-$R^2 = 0.20$].

Travel frequency is different from travel independence, as an individual may be a frequent traveler as a function of relying on assistance from others. Therefore, we explicitly asked the participants whether they limit their independent travel due to their vision and/or hearing impairment. Of the 56 low vision participants, 30 (54%) reported limiting their independent travel due to their vision impairment (Figure 1B, left panel), while only 2 (9%) of the 22 low vision participants with hearing impairment reported limitations due to their hearing impairment (Figure 1C, middle panel).

Of the 54 blind participants, 14 (26%) reported limiting their independent travel due to their blindness, and 8 (29%) of those with co-occurring hearing impairment reported limitations of travel independence due to their hearing impairment (Figure 1C, right panel). Blind participants with co-occurring hearing impairment were more likely to report an impact of blindness than those with normal hearing (39% vs. 12%, Figure 1B, right panel), and this hearing impact remains significant [$\chi^2(1) = 12.65$, $p < .001$] in a multiple logistic regression model that included age, onset of vision loss, gender, mobility limitation, and history of O&M training. In addition, participants who were older, with earlier onset of vision loss, and with co-existing physical condition that affects mobility, were less likely to limit their travel due to their blindness. The pseudo-R^2 of the full regression model reached 0.70. Table 2 provides the full regression results.

Sound Localization and Utility of Hearing Aids

To understand sound localization difficulties in these groups, the 73 participants with hearing impairment (23 with normal vision, 22 with low vision, and 28 with blindness) were asked

Table 1. Participant Self-Reported Characteristics.

	Normal vision		Low vision		Blind[a]	
	Normal hearing	Impaired hearing	Normal hearing	Impaired hearing	Normal hearing	Impaired hearing
N	28	23	34	22	26	28
Age, *M* (*SD*), years	49 (21)	75 (5.9)	57 (16)	68 (18)	52 (12)	60 (15)
Female, *N* (%)	19 (68%)	16 (76%)	19 (56%)	13 (59%)	19 (73%)	13 (46%)
Vision loss onset, *M* (*SD*), years	–	–	29 (27)	43 (34)	7 (12)	10 (16)
Hearing loss onset, *M* (*SD*), years	–	54 (21)	–	47 (28)	–	37 (26)
Physical problems limiting mobility, *N* (%)	3 (11%)	13 (57%)	8 (24%)	9 (41%)	6 (23%)	13 (46%)
Orientation & Mobility training, *N* (%)	–	–	15 (54%)	10 (43%)	25 (96%)	26 (93%)

[a]In this study, participants were categorized as blind if they self-reported their vision as counting fingers, hand waving, light perception, or no light perception.

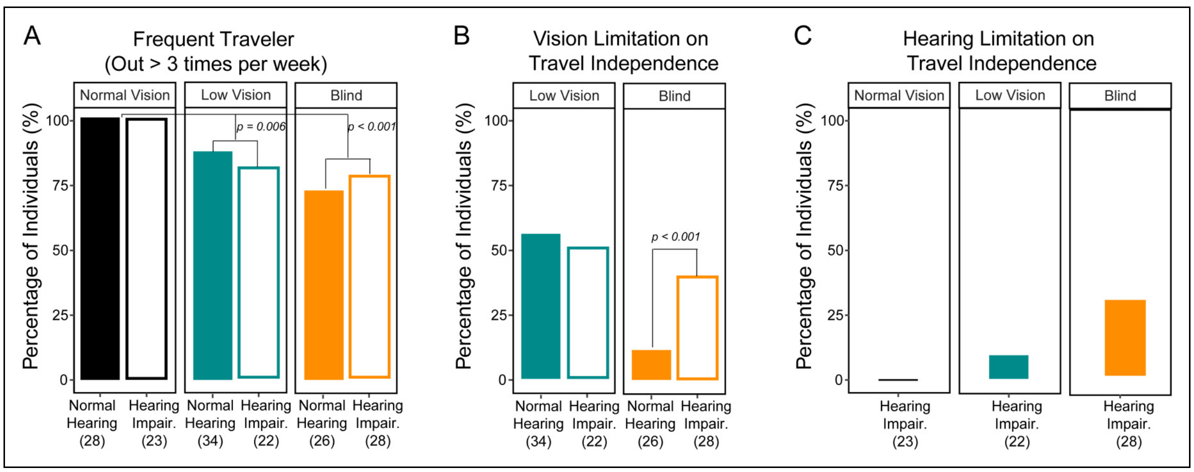

Figure 1. Travel Characteristics. A Number of Participants Responding to the Questions were Indicated in Parentheses. Questions Regarding Vision or Hearing Impairments were only Asked to Participants with Self-Reported Vision/Hearing Impairments. (A) Percentage of Participants Self-Reported as Frequent Travelers (Going Out at Least 3 Times A Week). (B) Percentage of Participants Reporting Impact of Vision Impairment on Travel Independence. (C) Percentage of Participants Reporting Impact of Hearing Impairments on Travel Independence.

Table 2. Logistic Regression Table on Travel Limitation due to Blindness.

	Estimate	Confidence interval (lower)	Confidence interval (upper)	Std. error	z_value	Pr(>|z|)
(Intercept)	1.81	−3.95	7.99	2.91	0.62	0.53
Age	−0.10	−0.21	−0.02	0.05	−2.24	**0.025**
Vision loss onset	0.16	0.08	0.30	0.05	3.07	**0.002**
Gender Male–female	0.19	−2.03	2.31	1.06	0.18	0.86
Physical limitation Yes–no	−3.19	−7.19	−0.58	1.60	−1.99	**0.047**
O&M training Yes–no	−1.31	−4.38	2.17	1.54	−0.85	0.40
Hearing loss Yes–no	4.52	1.74	8.75	1.72	2.64	**0.008**

to describe everyday scenarios where they found it difficult to localize things by sound. A total of 209 scenarios were generated by the 73 participants. Thematic analysis derived common challenges, with the most frequently recurring issues related to background noise, dynamic sounds (e.g., traffic), reverberation, multiple sounds, volume fluctuations, and adverse weather conditions (i.e., wind) (Figure 2A). Example description for each category is provided in Table 3.

As shown in Figure 2A, there were significant group differences in the percentage of participants reporting difficulties with dynamic sound [$\chi^2(2) = 8.23$, $p = .016$] and weather [$\chi^2(2) = 6.45$, $p = .040$]. Posthoc analyses showed a higher

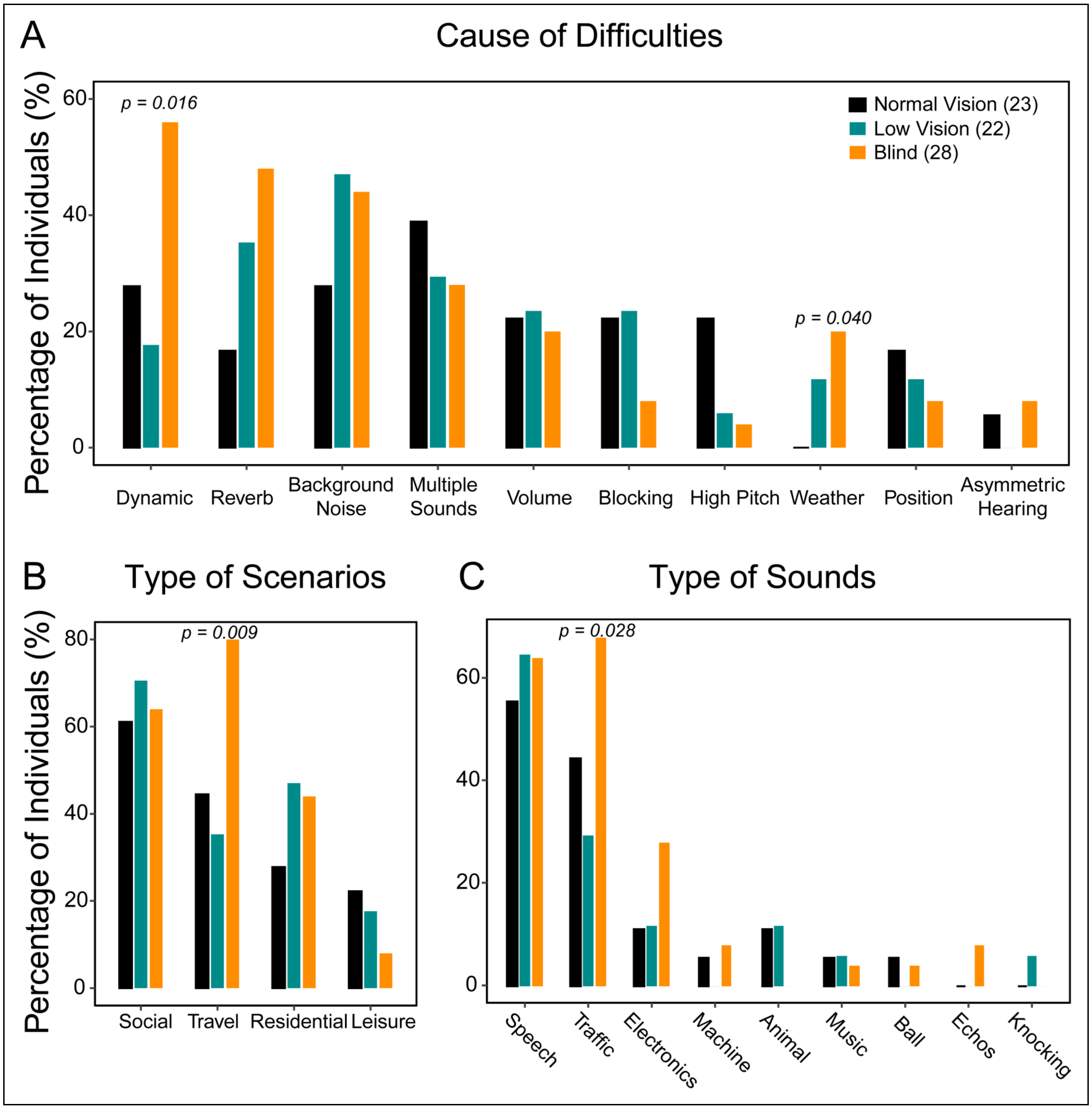

Figure 2. Thematic Analysis on the Perceived Sound Localization Difficulties Reported by Hearing Impaired Participants. A Number of Participants Responding to the Questions were Indicated in Parentheses. (A) Percentage of Participants Reporting Sound Localization in each Difficulty Category, in each of the Three Groups. (B) Percentage of Participants Reporting each of the Types of Scenarios, in each of the Three Groups. (C) Percentage of Participants Reporting each of the Types of Sounds, in each of the Three Groups.

percentage of blind participants reporting issues with dynamic sound than the low vision participants (56% vs. 18%, $z = -2.54$, $p = .033$). The emphasis on dynamic sounds by the blind participants is consistent with the higher incidences of report on travel-related scenarios (80% vs. 35%, $z = -2.98$, $p = .009$, Figure 2B) and traffic sounds (68% vs. 29%, $z = -2.60$, $p = .028$, Figure 2C) than the low vision participants.

All three groups showed high adoption of hearing aids, ranging from 59.1% of participants in the low vision group to 75.0% in the blind group (Figure 3A). Among the hearing aids users, the majority of them reported their hearing aids to be "always" helpful for speech perception (Figure 3B). However, fewer participants reported hearing aids to be "always" helpful for sound localization (Figure 3C). Generalized linear regression model on the perceived utility of hearing aids showed a significant main effect of task [speech vs. sound localization, $\chi^2(1) = 10.51$, $p = .001$], and a significant interaction between group (normal vision, low vision, and blind groups) and task [$\chi^2(2) = 5.96$, $p = .050$, pseudo-$R^2 = 0.23$]. Posthoc comparison showed that the low vision group was equally satisfied with speech perception

Table 3. Examples of Patient-Reported Difficulties in Sound Localization.

Category	Description
Dynamic sound	"I have a hard time locating traffic if walking on sidewalk."
Reverberation	"In a very echoey place, like garage and locker room, everything sounds very loud and is hard to determine where specific sounds are coming from."
Background noise	"Restaurant is a hopeless situation because of the low signal to noise level … Talking at a public place is a challenge."
Multiple sounds	"Everything talks at home because both of us (note: participant and their spouse) are blind. Sometimes can't tell where a sound is coming from."
Volume	"Alarms that go off…. where they are located seem to take all the space, which make it difficult to localize."
Blocking	"When I am inside the house, it is hard to tell where outside sounds are from."
High pitch	"Grandchildren, especially the younger ones…"
Weather	"Outside when the window blows … hearing aids have the setting to block the wind, but not helpful."
Position	"When someone is behind me and talking, can't hear them or know where they are."
Asymmetric hearing	"When things are coming up on the blocked up ear, it seems like they're coming from the other ear."

and sound localization ($z = 0.40$, $p = .69$), however, significantly fewer blind participants (75% vs. 25%, $z = -2.95$, $p = .003$) reported their hearing aids to be always helpful for sound localization than speech perception. Interestingly, the normal vision group also had less favorable response on their hearing aids for sound localization than speech perception (59% vs. 17%, $z = -2.36$, $p = .018$).

Discussion

Previous literature reported a dominant role of vision impairment on the independent functioning in individuals with DSI for at-home activities (Brennan et al., 2005; Keller et al., 1999; Lin et al., 2004). Our study extends this literature into travel context across a broad range of vision status. Our results show that the low vision participants limit their independent travel due to their vision impairment, with little additional impact of co-occurring hearing impairment. However, for blind participants, their hearing impairment leads to a more prominent impact on their travel independence. The impact of hearing impairment on the blind individuals was further confirmed by their heightened concerns localizing traffic sounds in travel scenarios compared to other groups. Despite the high adoption rate of hearing aids in the blind participants, the utility of hearing aids for sound localization was significantly lower than for speech perception.

In O&M training for blind individuals, learning to analyze traffic volume, speed and direction through hearing is a critical component (Blasch et al., 2010; Emerson & Sauerburger, 2008). In our study, dynamic traffic sound in travel was raised as the chief concern by blind individuals with hearing impairment. Hearing impairments can lead to reduced sound intensity (Glyde et al., 2013), altered temporal cues for judging speed (Henry & Heinz, 2013), as well as altered binaural differences for judging direction and distance of traffic (Kolarik et al., 2016; Xiong et al., 2023). Some of these changes can be relearned, such as reestablishing auditory straight-ahead after asymmetric hearing loss (Keating & King, 2013; Mendonça, 2014) or be partly addressed by the amplification of sound through hearing aids, such as detection of traffic from a further distance. However, without the compensation of useful vision, spatial hearing tasks such as accurately locating or orienting toward desired sound sources remain difficult (Sheffield et al., 2023).

The need for restoring spatial hearing for blind individuals with hearing impairment highlights the importance of integrating hearing rehabilitation strategies in their O&M training. However, our findings on the self-reported utility of hearing aids revealed the gap in concurrent hearing rehabilitation for addressing this need. Although there was already a high adoption rate of hearing aids in our blind participants, the perceived utility of hearing aids for sound localization reduced significantly compared to for speech perception. The less favorable responses on hearing aids usage for spatial hearing was also shown in our normally sighted group, indicating that the desire for better spatial hearing is not unique to individuals with blindness. The reduced utility of hearing aids for spatial hearing likely comes from the historical emphasis on speech perception (National Academics of Sciences, Engineering and Medicine, 2016) and the alterations in spatial cues caused by hearing aids (Spencer et al., 2024). Furthermore, audiologists have faced significant limitations in their ability to assess spatial hearing, and there are no standardized test protocols or setups specifically designed for evaluating spatial hearing.

In recent years, as candidacy for hearing devices expands, experts recommend incorporating spatial hearing ability as a key component of auditory evaluations and follow-up assessments (Van de Heyning et al., 2017; Dillon et al., 2022). In response, companies are developing clinic-friendly speaker array systems for accessing spatial hearing in audiology clinics (Compton-Conley et al., 2004; Zurek et al., 2024). Simultaneously, virtual auditory environments and audio augmented reality systems are being explored to create tests and protocols that are more representative of everyday conditions (Beechey, 2022; Gilkey & Anderson, 2014; Mehra et al., 2020). Our findings suggest that blind individuals with hearing impairment may be a population that would greatly benefit from these advancements (Jorgensen et al., 2022).

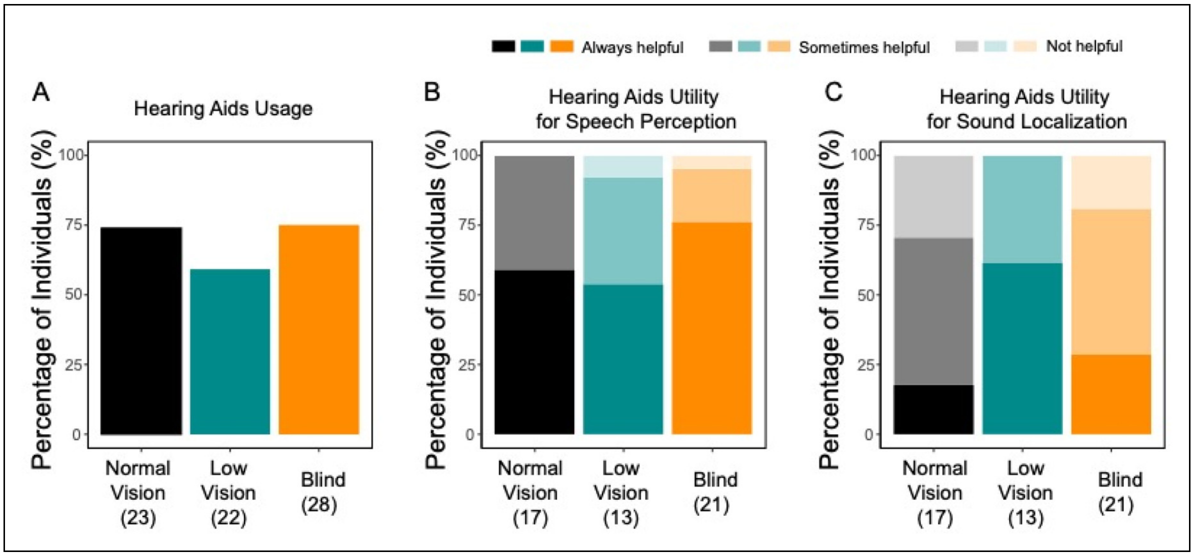

Figure 3. Adoption Rates and Perceived Usefulness of Hearing Aids by Hearing Impaired Participants. A Number of Participants Responding to the Questions were Indicated in Parentheses on the X-Axis. (A) The Adoption Rates of Hearing Aids in each of the Normal, Low Vision, and Blind Groups. (B) Perceived Usefulness of Hearing Aids for Speech Perception. (C) Perceived Usefulness of Hearing Aids for Sound Localization.

Although not formally included as a question in the survey, some of our blind participants reported that their hearing aids were helpful for some tasks but affected other tasks adversely, which led them to use their hearing aids selectively. Further, many blind participants mentioned the importance of echolocation (e.g., using external and self-generated echoes to judge direction and distance of objects) (Kolarik et al., 2014, Norman et al., 2021), and their personal experiences of the impact of hearing impairment on echolocation. Several blind participants shared successful experiences where their audiologists adjusted hearing aids settings in specific environments. As the hearing aids industry advances and provide more flexibility with individualized fitting options suitable for different environments, these personal experiences may prove invaluable when working with O&M specialists and audiologists in enhancing the utility of hearing aids on independent travel.

We acknowledge that there are several limitations of our current study. While we endeavored to characterize the participants' vision and hearing by their functional complaints, the lack of objective measures for many of the participants hinders the option for more fine-grained comparisons. Some participants shared detailed information on the model of their hearing aids, unilateral vs. bilateral fitting, and duration of wearing their hearing aids. However, we did not collect this information systematically. A future study should collect more detailed information on the hearing aids used which could provide insights into the recommendation of hearing aids. The use of a convenience sample in our participant pool may limit the generalizability of our findings, such as the hearing aids usage. The much higher adoption rates of hearing aids in our current study (70%) than previously reported (30%, Reed et al., 2023) may be due to a sampling bias of our study since the recruitment was primarily through university contacts (Weycker et al., 2021). It may also be due to an overall increase in hearing aids adoption after the availability of over-the-counter hearing aids (Lin & Reed, 2022).

In summary, we report an interaction between vision and hearing impairments affecting travel independence in individuals with low vision and blindness. The unique challenges faced by blind individuals, including increased limitations of hearing impairment on travel independence as well as the increased concerns with traffic sound, point to the importance of addressing hearing impairment in more dynamic environments and tasks beyond speech perception. The subset of individuals with blindness and hearing impairment may benefit greatly from the advancement in spatial hearing in hearing aids technology.

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ORCID iDs

Philip Reed https://orcid.org/0009-0006-4743-2398
Joseph Paul Nemargut https://orcid.org/0000-0001-6274-6172
Judith E. Goldstein https://orcid.org/0000-0001-7991-5913
Coral E. Dirks https://orcid.org/0009-0005-4084-531X
Yingzi Xiong https://orcid.org/0000-0001-7839-0019

Ethical Approval and Informed Consent Statements

This study was approved by the University of Minnesota Institutional Review Board (STUDY00001360) and followed the Declaration of

Helsinki. Verbal consent was acquired from each participant prior to their participation.

Consent to Participate

Verbal consent was acquired from each participant prior to their participation.

Consent for Publication

All authors have consented to the publication of this work.

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Data Availability Statement

The data will be available upon request to Yingzi Xiong (yxiong36@jh.edu).

Supplemental Material

Supplemental material for this article is available online.

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