Collaboration and Assistive Technology: Facilitating Joint Awareness for Noise Sensitivity

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Abstract

Existing research has explored various methods to support people with noise sensitivity (PWNS), from desensitization therapies to technological solutions. However, there is a gap in systems that identify and monitor characteristics of noise sensitivity experiences to help PWNS and their companions better understand their condition and make informed management decisions. To fill this gap, we developed AudioBuddy, an app with sensing and tracking features designed to promote awareness between PWNS and their companions. We tested AudioBuddy as a technological probe over a two-week field deployment. Our results show that AudioBuddy can support awareness of how sounds and environments influence the psychophysiological states of PWNS, aiding in understanding noise sensitivity experiences. Nonetheless, technical limitations impacted the depth of awareness participants could attain. We discuss challenges and opportunities for future systems to facilitate awareness among PWNS and their companions.

CCS Concepts

• **Human-centered computing → Empirical studies in HCI**; **Empirical studies in ubiquitous and mobile computing**; **Empirical studies in accessibility**.

Keywords

Noise Sensitivity, Wearables, Mobile Devices, Assistive Technology, Collaboration

ACM Reference Format:
Emani Hicks, Luc Rieffel, Ariya Gowda, Aehong Min, and Gillian R Hayes. 2026. Collaboration and Assistive Technology: Facilitating Joint Awareness for Noise Sensitivity. In *Proceedings of the 2026 CHI Conference on Human Factors in Computing Systems (CHI '26), April 13–17, 2026, Barcelona, Spain.* ACM, New York, NY, USA, 18 pages. https://doi.org/10.1145/3772318.3793203

CHI '26, Barcelona, Spain

ACM ISBN 979-8-4007-2278-3/26/04
https://doi.org/10.1145/3772318.3793203

1 INTRODUCTION

Noise sensitivity is characterized by an aversion to specific sounds (*i.e.,* misophonia), the perception of everyday sounds as excessively loud and/or painful (*i.e.,* hyperacusis), or ringing in the ear (*i.e.,* tinnitus). Between two and six percent of people have some form of noise sensitivity, with an estimated prevalence of between 38 and 45 percent among autistic people[1] [84]. Noise sensitivity experiences may manifest in early childhood [38, 78, 81] and continue well into adulthood [29, 33, 60], with people with noise sensitivity (PWNS) describing challenges in school and work environments and experiencing dysregulation or fatigue [29, 80]. Despite the prevalence of noise sensitivity, the general population, professionals, and caregivers [3, 25, 29] can be unaware of what factors cause it and how technology can help.

Human-Computer Interaction (HCI) research on supporting individuals with sensory differences has focused on inclusive environments [57], and stress reduction [68], using wearables [1, 27], mobile applications [14, 71], and virtual environments [31, 72] to support individual self-regulation. Prior literature highlights the importance of collaborative care for successfully managing health and well-being long-term [12, 69], aligning with an interdependent and mutual care framework [5, 59, 93]. This model supports PWNS to not only be aware of and manage their health but also to have others who are aware and can provide support. Building on our framework of awareness [30], we examine how technology can support three types of awareness: self-awareness, others' awareness, and joint awareness.

We developed and tested AudioBuddy, a tracking system (see Figures 1 and 2) with mood logging, coping activities, ally notifications, health alerts, and personalized activity reports [42]. AudioBuddy tracks emotional states via mood check-ins, monitors environmental noise levels, alerts on detection of elevated heart rate, and suggests coping activities for self-regulation, while supporting information sharing and facilitating others' awareness, co-regulation, and co-management. This approach aligns with previous principles of monitoring psychophysiological states and providing multi-modal

[1]The use of person-first or identity-first language has been a topic of discussion within the autism community[11, 53]. Here and throughout, we use identity-first language based on previous research for preferences in the U.S. [92] and personal experience (first author).

feedback about environmental triggers to foster awareness [30, 41]. We assess (1) the system's usefulness in supporting self, others', and joint awareness through participants' combined use, and (2) ways to enhance joint awareness between PWNS and their companions.

We recruited PWNS (n = 11, age 11-62) and their companions (n = 7, age 29-62) for a field deployment. Analysis of participant interviews indicates that data-driven reflection on environmental and psychophysiological data may have fostered awareness and understanding of the influence of environmental stimuli, emotional states, and environmental thresholds. However, technical limitations — particularly the lack of data granularity, such as specific types and characteristics of sounds — were perceived to impact the degree of awareness and understanding. Based on our findings, we discuss the technological challenges in tracking noise sensitivity experiences for awareness, as well as opportunities for supporting greater joint awareness.

This deployment study contributes:

- Empirical evidence that systems incorporating data-driven tracking, reflection, and noise alerts can help facilitate awareness of noise sensitivity experiences, supporting the design of technologies that enable awareness and collaboration among PWNS and their companions.
- Design implications for future systems that facilitate awareness for collaborative management of noise sensitivity, including the need for broader joint awareness across settings and opportunities for intelligent systems to enhance awareness capabilities for PWNS and others.

2 BACKGROUND

In this section, we provide background on noise sensitivity and review prior research on technological approaches for sensory differences and awareness, and the use of technology for collaborative care. Our research builds on these areas to explore opportunities for technology support to raise awareness of noise sensitivity experiences, promote understanding and self-management, as well as collaborative management.

2.1 Background on PWNS' Experiences of Noise Sensitivity

When examining misophonia and hyperacusis symptoms in autistic and non-autistic adults, Scheerer *et al.* [84] found that across participants, both general (*e.g.,* hyperacusis) and specific (*e.g.,* misophonia) sounds can cause adverse responses, with sounds including everyday sounds (*e.g.,*traffic noise, crying, crowd noise), human-produced sounds (*e.g.,* chewing/eating, talking, coughing, certain consonant sounds, etc.), animal/insect sounds, repetitive sounds, and loud and/or sudden sounds. While such sound intolerance is common among PWNS, experiences are not generalizable; sound aversions are unique to each individual, and some aversions are unknown until encountered [29].

Schools, workplaces, grocery stores, and social settings (*e.g.,* parties, clubs, family functions) can be disabling and inaccessible for PWNS [30, 65, 80]. PWNS report experiencing pain and discomfort, sensory overload, and overstimulation from problematic sounds and environments, leading to dysregulated states, elopement, and, when necessary, masking discomfort to remain in an environment [13, 30, 90]. During times of discomfort, PWNS tend to use sound-blocking or masking technology, such as earmuffs and noise-canceling headphones; however, these options are not always available or adequate. Moreover, PWNS are not always aware of when an environment has become overstimulating, cannot consistently anticipate the occurrence of problematic sounds, or may not be aware of what sounds are problematic. These accounts indicate a need for greater awareness of noise sensitivity to better understand the contexts of PWNS' sensory experiences and how others can collaborate with PWNS to manage their responses and the environments around them. With these experiences in mind, we designed and developed AudioBuddy, a practical and novel application using commercially available hardware to facilitate awareness and regulation among PWNS and their care networks of the potential effects of noise on their well-being.

2.2 Technological Approaches for Sensory Sensitivities and Sound Awareness

Most research on sensory sensitivities has focused on individuals who identify as autistic [19, 22, 49, 58, 64, 76, 97]; although some studies have also considered related neurodivergent groups such as those with Attention-Deficit/Hyperactivity Disorder (ADHD), as well as individuals with various chronic illnesses and disabilities [36, 62, 63]. These studies indicate that technologies—including recommendation systems, robots, and wearables—can support safe movement, communication, cognitive load management, and mental health care concerning diverse sensory sensitivities (*e.g.,* lighting, noise, and movements). Emerging technological solutions could be vital in addressing sensory processing challenges, particularly through self-management and joint management approaches. For instance, Deep Pressure Therapy techniques have inspired the development of a breathing awareness technology that applies pressure to the torso for individuals with sensory sensitivities [51]. Others have used technology to mediate emotion regulation [1] for people with sensory processing sensitivities and the use of sensor fusion and machine learning for autistic children to help manage their sensory responses in a classroom [22]. Overall, research suggests that technology can provide some level of support for self and collaborative management of noise sensitivity experiences, but systems that support awareness of surrounding contexts are still needed, given the importance of awareness for regulation and health management [30].

Research on sound sensitivities and/or awareness has so far been mostly isolated to the D/deaf and hard-of-hearing (DHH) community to support sound awareness and recognition [26, 35, 43, 46–48]. For instance, Jain *et al.* [48] developed and deployed HomeSound to support in-home sound awareness for DHH users, providing visual and haptic feedback of sound characteristics for supporting self and sound awareness for users to identify sounds occurring in their home. This approach shows promise for supporting sound awareness, but so far has been limited to home contexts. Huang *et al.* [43] explores the potential of mobile AI sound awareness systems, using deep learning models to classify sounds to support environmental awareness for DHH people using smartwatches. Similarly, Liu *et al.* [86] applied a deep convolutional neural network (CNN) model to enable context-independent event recognition for a smartphone-based acoustic sensing and notification app. Evaluations of these prototypes demonstrate the feasibility of facilitating sound awareness for DHH individuals in various environments and the utility of using mobile and wearable devices to do so. Motivated by these prior sound awareness strategies, we extend this work by exploring sound awareness approaches beyond the DHH community, focusing on supporting sound awareness for PWNS and their companions, and examining how technology can facilitate awareness of problematic sounds.

With AudioBuddy, we explored how smartwatches and mobile devices, which are commercially available products, could mediate awareness and collaboration among PWNS and their companions. By incorporating regulation strategies and monitoring of health and environmental data, we facilitated awareness and regulation of noise sensitivity experiences, indicating the affordances and limitations for supporting PWNS.

2.3 Towards Collaborative Care for Noise Sensitivity Experiences

Mobile (*e.g.*, [6, 16, 56]) and smartwatch applications (*e.g.*, [20, 21, 70]) have been used to aid in tracking relevant personal data, which increases awareness and knowledge of an individual's health and well-being. For example, the use of wearables in particular is increasingly popular for tracking health and fitness data [17, 91], as these tools grant everyday people access to data that is typically available through physicians, such as heart health data [54]. Similar trends in prior studies highlight the value these devices provide in health management [73, 82, 85] because they are discrete, enable multi-modal feedback, and provide personalized data tracking for self-knowledge. However, many of these support approaches focus on the individual and how they self-manage. In this work, we focus not only on the individualized approach to managing noise sensitivity through self-monitoring with mobile devices and smartwatches, but also on the collaborative and contextualized nature of doing so. In particular, we focus on data tracking for the collaborative management of noise sensitivity experiences and build on the collaborative tracking research that follows by exploring how technology can support collaborative care for noise sensitivity experiences.

Scholars have developed systems for collaborative tracking of relevant data between people with health conditions and their caregivers. In particular, single and multi-device tracking systems enable collaboration between people with health conditions and others [15, 50, 67, 88]. For example, use of FluidTrack [67] to support parent-child collaborative tracking enabled children to contribute actively to health data capturing and tracking, demonstrating the feasibility of FluidTrack to support parent-child collaborative tracking. Similarly, CoolTaco [88], a smartwatch-phone system, allows co-regulation among families through a task-setting process to help with environmental stimulus reactions. The evaluations of these systems demonstrate the utility of mobile and wearable systems in collaborative management of health conditions, but are limited to parent-child relationships, lacking inquiry into other caregivers and allies (*e.g.*, spouses), who also provide care and support.

Collaborative health management relies on the alignment between individual goals and the shared values of collaborators [7, 12], with this alignment shaped by the awareness of both the individual and their collaborators. PWNS need to be aware of and manage their health, but also have others who are aware to help in managing when needed. Three types of awareness support PWNS: self-awareness, others' awareness, and joint awareness [30]. Joint awareness is achieved through information sharing between PWNS and others to enable collaborative management and regulation of noise sensitivity experiences. Wearable and mobile technology have the potential to facilitate awareness between PWNS and others of noise sensitivity experiences [41]. We build on this prior research by testing the actual utility and feasibility of such technologies. Specifically, we explore the feasibility of mobile and wearable assistive technologies to facilitate awareness of contexts that provoke noise sensitivity experiences through the evaluation of AudioBuddy in the wild.

3 SYSTEM OVERVIEW

We developed AudioBuddy, a mobile application for semi-automatic data tracking to support the facilitation of awareness of factors indicating and evoking noise sensitivity experiences. In this section, we review the process that informed the design of AudioBuddy and its features and implementation.

3.1 Informing the Design of AudioBuddy

The design of AudioBuddy was informed by our interviews and co-design sessions with PWNS and their allies [28, 30, 41]. This prior work surfaced three key takeaways that informed our approach and design rationale for specific features of AudioBuddy (see Table 1).

Based on these design requirements and sketches, we developed a preliminary version of AudioBuddy. To evaluate the user interface design and its suitability for our broad user groups (*i.e.,* accounting for neurodiversity and age), we conducted preliminary end-user testing and semi-structured interviews virtually with PWNS (n =12) and companions (n = 5). Feedback included improving the data logging feature to include more moods and improving data visualization. We iterated on our design to include additional moods recommended by the end users, mood categorization, and distinct colors for each mood for better visualization in the activity report. We added color to the feature buttons to help users associate app features by color and text, versus text alone. Overall, before these changes, evaluators reported the system design to be simple and easy to navigate regardless of age and neurotype.

Finally, before our deployment, we piloted AudioBuddy with experts in user experience research (n = 3), with two of them having existing noise sensitivities, for one week. Participants found the flow of AudioBuddy understandable and easy to use, but identified some bugs (*e.g.,* navigation issues, loading errors, and data syncing issues), which were fixed prior to the deployment. Pilot participants did not participate in the rest of the study.

3.2 AudioBuddy

AudioBuddy is implemented on Apple iOS and was deployed using an Apple Watch SE to automatically track physiological (*e.g.*,

Table 1: Formative Findings that Informed the Design of AudioBuddy

Research Findings	Rationale	Design Approach	AudioBuddy Feature
PWNS experience sensory overload/fatigue from extended exposure, unknown triggers, and, at times, unawareness of emotions/physiological states.	Technology should support self-regulation.	Digital toolbox that suggests coping strategies; brings attention to emotional and physiological states.	Coping activity toolbox with suggested strategies. Overview of tracked data that includes noise level, heart rate, mood, and intensity of mood.
PWNS and others are not always aware of or understand experiences, triggers, and/or impacts (e.g., sensory overload/fatigue, anxiety, etc.).	Technology should increase the awareness of PWNS and others of psychophysiological states and environmental contexts.	Sensing and tracking relevant information; notifications alerts for exceeded thresholds.	Tracks noise level, heart rate, mood, and intensity of mood. Notification when there is an increase in noise and heart rate over a certain threshold.
Supporting (e.g., managing and regulating) noise sensitivity needs a more collaborative approach.	Technology should enable collaborative management and regulation.	Notification to allies; information sharing	Notification when there is an increase in noise and heart rate over a certain threshold. Community section that includes someone you'd want to contact during stressed states. Can share data or notify a community member.

heart rate) and environmental (*e.g.*, noise level) data, along with an iPhone that tracks self-reported psychological information and provides data visualizations. All tracking data was saved using Google Firebase database in real-time, unless users' devices were offline, in which case their data was cached and synced later.

AudioBuddy aims to increase awareness of contexts that may indicate distress due to noise sensitivity and offers coping activities for managing these situations when needed. It operates in two modes: (1) an event-triggered scenario, sending a notification to the user's watch and phone when their heart rate or ambient noise level exceeds the personalized threshold, prompting users to engage with AudioBuddy; and (2) manual mode, in which the user can proactively engage with the app. AudioBuddy includes a list of coping strategies, such as breathing exercises, listening to music, meditation, and engaging in physical activities. The system also promotes awareness through emotion check-ins, journal entries, and data visualizations. Finally, users can share their information with someone in their care network to foster joint awareness, empower self-advocacy, or enable collaborative management and regulation strategies when needed.

3.3 Mood Check-ins

AudioBuddy allows users to track their moods to facilitate awareness of how they are doing throughout the day and over multiple days. Users can log their moods in response to a reminder or proactively at any point. Reminders are sent automatically at 8:00 am, 12:00 pm, 4:00 pm, and 8:00 pm. To log their mood, users first indicate how they are feeling based on four mood categories: "Good," "Okay," "Not Good," or "Bad" (see Figure 1B). They then can choose one of four emotions that best describe how they are feeling. For example, if the user selects "Good" the four emotions that they can choose from are "Excited," "Happy," "Silly," or "Energetic" (see Table 2). If the four emotions provided are not descriptive of the person's affective state, an "Other" option is available within each category, allowing the user to enter an alternative emotion. After selecting an emotion, the intensity of that emotion is chosen on a scale from 1 to 10, with higher values indicating greater intensity. Finally, a journal entry with the question "*What's on your mind?*" requires users to reflect and provide a more descriptive understanding of their affective state. When affective states that are "Not Good" or "Bad" are entered, the system suggests engaging in a coping activity (see Figure 1C). Upon completing a mood check-in, AudioBuddy displays their latest mood on the home screen under "Today's Activity Review" (see Figure 1A). Prior moods can be viewed under their Activity Report for the day (see Figure 1D).

Table 2: Mood Check-in Categories and Emotions

Mood Category	Emotions
Good	Happy, Excited, Energetic, Silly
Okay	Bored, Neutral, Peaceful, Hopeful
Not Good	Annoyed, Sick, Tired, Sad
Bad	Stressed, Anxious, Angry, Frustrated

3.4 Notify Ally

The Notify Ally feature facilitates awareness between PWNS and selected companions during times of distress, such as dysregulated states or prolonged exposure to overstimulating environments. Users can provide the contact information of their companion(s)

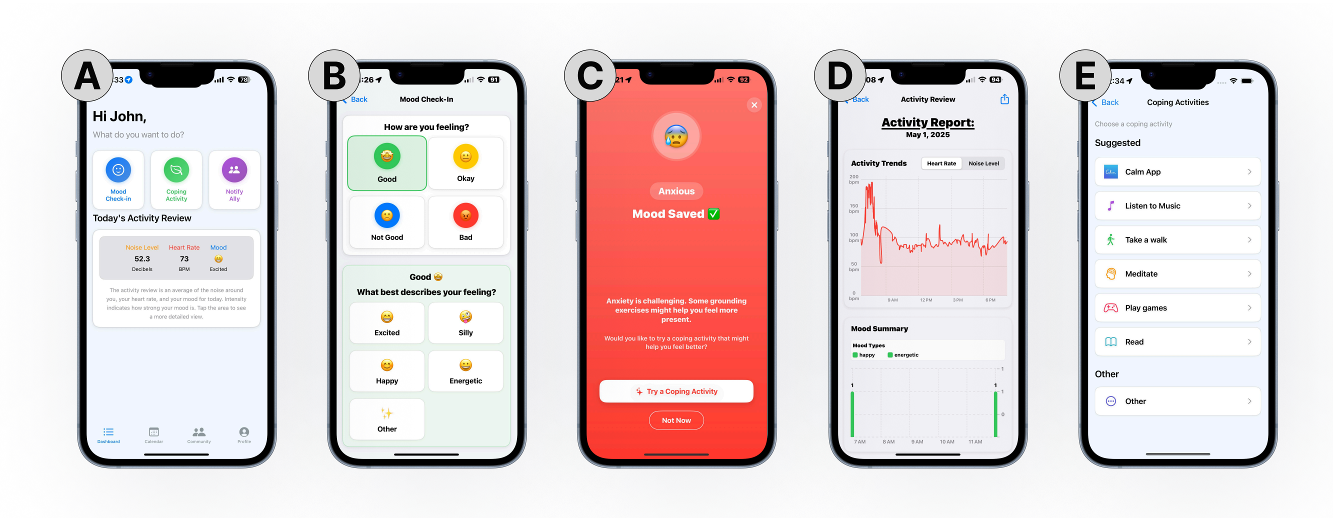

Figure 1: (A) Home Screen. Screen A is of the home screen with mood check-in, coping activities, notify ally buttons, as well as an overview of the day's activities. (B) Mood Logging. Screen B shows four mood categories, with the good category selected and four emotions for users to choose from (Excited, Silly, Energetic, and Happy). (C) Mood Saved Confirmation. Screen C is of the mood saved screen after selecting a negative mood, in this case, anxious, with the option to try a coping activity. (D) Activity Report. Screen D is of an activity report showing the user's heart rate trend for the day and moods logged. (E) Coping Activities. Screen E shows the list of coping activities.

to be added to their community and select how they would like notifications to be delivered, via iMessage, email, or both (see Figure 2F). When the PWNS is in an environment that is overwhelming or is experiencing difficulty in self-regulating, they can select to notify someone from their community (see Figure 2G). Additionally, when receiving a local alert on their own devices of an increased heart rate or noise level in their environments, they can choose to alert a companion by selecting "Notify Ally" (see Figure 2H), providing the user's location and the latest available health data (*e.g.*, heart rate and noise level) with further instructions. For example, the notification may read:

> URGENT: Your ally, Sally, needs your attention!
> Hello John, Your ally Sally has requested your attention. Please check the information below and reach out to them as soon as possible.
> Time of Request: May 4, 2025 at 6:00:53 PM
> Location Information:
> Address: 123 Main St, Anytown,
> CA 90210 United States
> Coordinates: XX.XXXXX, -XX.XXXX
> Time: May 4, 2025 at 6:00:52 PM
> Health Information:
> Heart Rate
> Current: 78 BPM
> Time: May 4, 2025 at 5:54:25 PM
> Environmental Noise
> Current: 71 dB
> Time: May 4, 2025 at 5:56:26 PM

Notifications sent via email are sent automatically; however, iMessage alerts can be edited by the users to include any additional information if necessary.

3.5 Coping Activities

To support self-regulation, AudioBuddy offers users six coping activities based on prior research [29, 30, 65]: reading, playing games, meditating, taking a walk, listening to music, or opening the Calm App. When users select to listen to music or use the Calm App, AudioBuddy launches external apps (see Figure 1E). After selecting an activity, the user is expected to engage in that activity. The system prompts them after 15 minutes to log their mood to indicate if the coping strategy helped and/or if additional support may be needed.

3.6 Health Monitoring and Personalized Alerts

Prior work has indicated correlations between increased heart rate and noise sensitivity [23], as well as interest by PWNS to monitor their heart rate to understand how their body may respond during dysregulated states [40]. AudioBuddy supports data-driven reflection by incorporating data visualizations of logged heart rate and environmental noise levels (see Figure 1D). The system integrates with Apple's Health app and notifies end users when heart rate and noise level measurements exceed their personalized noise and heart rate thresholds, which are set by the user within their profile.

3.7 Personalized Activity Reports

To facilitate self-awareness, users can review their data through a calendar view or daily Activity Reports (see Figure 2I). Users can view their heart rate and noise level trends and a summary of their

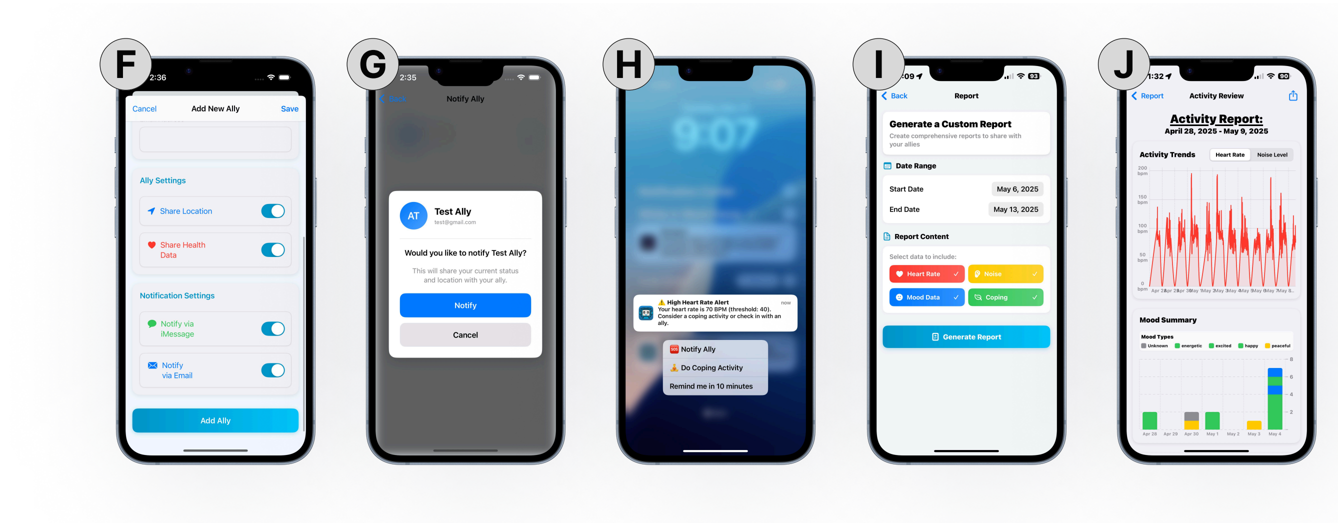

Figure 2: (F) Notify Ally Settings. Screen F shows how notify ally messages can be sent, via email or iMessage, as well as what information to include in the message, such as the latest health data and location. (G) Notify Ally Confirmation. Screen G shows a pop-up message to confirm whether the user wants to notify their ally. (H) High Heart Rate Alert. Screen H shows a high heart rate alert with options to notify ally, do a coping activity, or remind the user later. (I) Generate Custom Report. Screen I shows options to generate a custom activity report, where users have the option to select a date range and the data they would like to include in the report. (J) Generated Report. Screenshot J shows the output of a generated activity report.

mood and coping activities for the day. Custom Reports can be generated to view their data over selected time periods (see Figure 2J). AudioBuddy provides data-sharing to facilitate joint awareness and communication among PWNS and companions through shared snapshots of reports.

3.8 AudioBuddy and User Privacy

AudioBuddy accesses sensor data from smartwatches and mobile devices equipped with "always on" sensors that continuously collect user data. To address privacy concerns, only necessary sensors were activated by users. For environmental noise monitoring, AudioBuddy integrates data collected from Apple's Noise App, which only measures decibel levels without recording environmental audio, protecting users and bystanders from unwanted surveillance. To address privacy concerns about sharing personal data with others, AudioBuddy lets users manually choose and edit what data is shared with their companions before sending alerts or reports.

4 METHODS

We conducted a field deployment of an assistive mobile application to facilitate awareness with eleven PWNS and seven companions from April 2025 to June 2025. We instructed companions to use the app as they would to support awareness of their own moods, with the goal of understanding how the design of such a system might support companions' awareness of their own state, as well as respond to the needs of the PWNS. Data were collected through the watch and phone, and semi-structured interviews were conducted four times during the study period. The first author's university's Institutional Review Board approved our research study. The following subsections describe our study participants, procedures, and approach used for data collection and analysis.

4.1 Participants

We recruited eleven PWNS, some of whom are also companions, and seven companions, including parents and spouses/romantic partners, through a clinical center for neurodivergence and a regional non-profit center contracted by the State of California to coordinate lifelong services. Prior to participating in the study, participants signed a consent form, and children provided verbal assent. We enrolled two families and six dyads. Families consisted of two parents and one child. Dyads typically consisted of one person with noise sensitivity and their companion, which included three parent-child pairs and one romantic partnership. Two parent-child dyads both had noise sensitivity and were mutual companions. Table 3 presents details of our study participants.

After completing the study, participants received either cash compensation or kept the loaned smartwatch. Participants received $25 per week, or $100 for the complete four weeks of the study. For completing all surveys, participants received $66 at the end of the study. For participation in the final interview, they received $50. Altogether, participants were compensated up to $216 if they completed all study activities. Through the remainder of the paper, we use N# to refer to a person with noise sensitivity, and C#[2] to refer to a companion.

[2]Some noise-sensitive participants (N1, N4, N8) were also companions for their children. However, we only count them once.

Table 3: Participant Summary and AudioBuddy Use

ID	Age, Gender	Companion	Misophonia Score	Hyperacusis Score	Mood check-ins	Coping Activities	Notify ally
N1	39, F	C2	93	38	18	2	1
N2	11, F	N1	59	23	18	5	0
N3	13, M	N4	31	22	25	5	0
N4	46, F	N3	68	39	26	0	0
N5	11, M	C4, C5	36	36	18	6	0
N6	16, F	C3	86	46	56	2	1
N7	30, F	C1	87	50	25	3	0
N8	62, F	N9	87	45	30	2	0
N9	28, M	N8	74	49	11	0	0
N10	12, F	C7	18	34	13	0	1
N11	15, M	C6	81	35	12	0	0

4.2 Study Procedures

Participants who owned Android devices were provided with an Apple Watch SE (Gen 2) and an iPhone SE for the duration of the study. For participants who owned an iPhone but did not have an Apple Watch, one was provided for the duration of the study. We also offered watch bands with different textile features to accommodate some individuals' sensory sensitivities.

Participation in the study was adapted based on participants' availability and preferences for up to four weeks (see Figure 3). We conducted interviews with participants at four points during the study (app installation, mid-study, app review, and exit) to gain an understanding of experiences using the application, focusing on various aspects of noise sensitivity, technology use and adoption, and technological improvements for facilitating awareness of noise sensitivity.

During Week 0 (see Figure 3), we conducted a 60-minute enrollment interview, during which we provided an overview of the study and obtained and confirmed participants' consent to participate in the study. During the study enrollment session, we reviewed the study procedures and purpose with all participants and confirmed their interest in participating, reminding them that they could withdraw consent at any point.

We collected noise sensitivity data via two validated assessment tools: The Sussex Misophonia Scale for Adolescents and Adults (SMS-Adolescents, SMS- Adults) [78, 89], and an adapted Hyperacusis Assessment Questionnaire [77]. The SMS-Adolescents was completed by participants ages 17 and under (n = 6), while the SMS-Adults was completed by participants ages 18 and older (n = 5). The SMS is a scale used to evaluate misophonia, and has been validated with both adolescents [78] and adults [89]. The questionnaires have two parts. Part 1 includes 48 misophonia trigger sounds in eight categories (*e.g.,* the sounds of people eating, the sound of repetitive tapping, the sound of rustling, throat sounds, sounds people make through their mouth and nose, some voice sounds, repetitive visual movements, and some background sounds) and participants are asked to indicate whether they hate them or do not mind them. Participants could respond either "Yes" if they hated the sounds or "No" if they did not mind the sounds for each category. If a participant responded "Yes" to any category, then they could select which sounds were triggering within that category and, when necessary, select "Other" and provide additional triggering sounds. If a participant responds "No" they move to the next question. Part 2 of the survey presents 39 Likert-scale statements about behaviors, emotions, and outcomes of misophonia, which are preceded by the question "*How often do these things happen to you?*" Examples include: "*Sometimes I leave the room, to avoid telling people off for making bad sounds*" (Item 7) and "*I'm worried about always having problems from hearing certain sounds*" (Item 23). Responses are given on a 5-point scale and summed for scores ranging from 0 to 156, where the diagnostic passing threshold indicating clinically significant misophonia is 49 or higher for adolescents [78] and 51 or higher for adults [89].

Participants completed an adapted version of the Hyperacusis Assessment Questionnaire (HAQ)[3] to evaluate the severity of hyperacusis in terms of loudness, fear, and pain [77]. It comprises 14 items scored on a 5-point Likert scale. Examples include: *"I perceive louder sounds as annoying"* (Item 1) and *"It is definitely too loud for me at concerts, cinema, or sports events"* (Item 5). The global score is the sum of the 12 items, with a higher score indicating higher hyperacusis severity.

The SMS indicated that out of the eleven participants who self-reported noise sensitivity, four children (M score = 75, SD = 14) and four adults (M score = 82, SD = 10) exceeded the diagnostic threshold for misophonia [89]. The HAQ revealed that most participants had high scores in the Loudness Hyperacusis subscale, where the mean score was 21, with a maximum possible score of 28 points. This indicates that most PWNS (n = 7) in our study may perceive everyday sounds as excessively loud.

After completing the surveys, participants received an Apple Watch and/or a smartphone for the study, without the AudioBuddy

[3] Although this assessment was evaluated with individuals with tinnitus, it assesses hyperacusis in terms of loudness, fear, and pain, which are commonly experienced by individuals with noise sensitivity [34].

Figure 3: Four-Week Deployment Study Overview. Week 0 participants engaged in a study enrollment interview and were given devices. Week 1 apps were installed on devices. Week 2 participants' mid-week interview. Week 3 participants were interviewed on their experiences using the app and ended their testing of the app. Week 4 participants engaged in an exit interview and gave devices back if they were not keeping them for compensation.

application installed. The first week of the study was used to mitigate the potential novelty effects of having the study devices.

One week later (Week 1 in Figure 3), we conducted a 90-minute interview to gather information about PWNS participants' awareness of triggers and effects, current management practices, and how others, such as their companions, support them. We also discussed how they managed any situations that caused noise sensitivity experiences in the prior week. Interviews were conducted separately for adult PWNS and companions. For PWNS who were 17 and younger, their caregivers had the option to remain in the room during their child's interview; six allowed their child to be interviewed alone. Furthermore, for participants who were given study devices (*e.g.*, Apple Watch and/or iPhone), we discussed how they perceived and used the study devices. We then installed the AudioBuddy application and reviewed its features, providing opportunities for questions when needed. Participants were encouraged to interact with the app and set up their study companion as their ally in the community feature. We advised participants to do as many of the prompted mood check-ins as possible in their day-to-day schedule. We encouraged companions to consider how they would prefer to interact with the app to facilitate their own self-awareness, as well as awareness of PWNS experiences, to support joint awareness and cooperative management of noise sensitivity experiences.

In week two, we conducted 30-minute interviews to discuss experiences with the app, address any challenges, and answer questions about the application or the study in general. At the end of each participant's testing period (Week 3 in Figure 3), we conducted a 90-minute interview to review their experience using AudioBuddy for supporting noise sensitivity awareness for both PWNS and their companions.

We concluded the study with a 60-minute interview the following week, during which participants provided any final feedback on their experiences and returned their devices if they had decided to receive cash compensation instead of the watch. During most interviews, two researchers were present, with one leading and the other taking observational notes. After each interview, the interviewer wrote memos to capture additional observations.

4.3 Data Analysis

Interviews were recorded with consent for later transcription and analysis. One participant asked not to record, and we relied on observation notes and memos for analysis. We applied a reflexive thematic analysis approach [9, 10] in which we inductively and deductively coded the data by extracting relevant quotes, key points, and preliminary interpretations in accordance with the use cases of AudioBuddy and the three types of awareness outlined in our prior work [30]. First, three researchers read interview transcripts and observation notes for two participants and extracted quotes that were representative of participants' experiences using AudioBuddy and the three types of awareness. Then, the researchers met virtually to discuss the transcripts and their preliminary analysis. Using Miro[4], the authors conducted affinity diagramming with the excerpts. To manage the volume of digital sticky notes, we used Miro's AI cluster feature as an organizational tool to organize digital sticky notes based on their keywords. For example, quotes mentioning mood or emotion were grouped. This AI-assisted organization served a logistical purpose, making it easier to identify relevant quotes, rather than serving as an interpretive assistant. We did not use these groups in our analysis. Instead, we analyzed each quote and grouped it based on our understanding of the context surrounding the quote and our interpretation of the data. For example, the following quote was automatically clustered with other quotes about noise; however, we coded it as "environmental awareness" in our analysis.

> *"Working in the same location every day helped me realize I know the location is loud, but I didn't know how loud, so having that kind of visual confirmation, like, oh yeah, this is a really loud store. It's kind of just cool to see."*

Our analysis produced a group of topics that formed our initial codebook. The same researchers then used this codebook to code the remaining data, meeting weekly to discuss and review the codebook. These discussions provided space to interrogate differences in readings of the data, refine identified themes, and ensure that no single researcher's perspective dominated the analysis. This process eventually resulted in a final codebook consisting of 8 parent codes and 56 sub-codes. For example, the parent code "impacts on awareness" included "attuned to sensitivities," "environmental awareness," "emotional awareness," and others. The coded data and codebook were used to inform our themes on how AudioBuddy

[4] https://miro.com/

supports and facilitates awareness for PWNS and their companions. We further refined our themes during the writing process, resulting in the topics presented in Section 5.

4.4 Limitations

Circumstances surrounding the recruitment of participants influenced data collection procedures. In particular, it was difficult to recruit both people with noise sensitivity and a companion for the study. Therefore, although we had originally intended only to enroll people already familiar with Apple devices, we enrolled participants with noise sensitivity who used a different operating system than iOS, requiring them to use a loaned phone during the study. Using AudioBuddy on devices that were not their personal devices likely impacted when and how participants engaged with our system. Likewise, as in any study of this type, participants already recognized themselves as having noise sensitivity and were motivated to improve management of the condition, which may impact their engagement with the application and limit the transferability of our findings to less motivated or aware people.

We used Apple's smartwatch for tracking environmental data, which does not support capturing and tracking low-volume sounds that may be problematic for some people. Specifically, we were unable to capture dynamic sound characteristics beyond loudness described as problematic by some PWNS (*e.g.*, mouth noises, dog panting). Future work could explore additional methods to design systems that improve awareness and management of noise sensitivity, considering the different types of sounds that may be problematic.

During data analysis, we used Miro's AI as an organizational tool to aid in organizing digital sticky notes into groups based on their keywords. Although we did not use these groupings for analysis as we conducted affinity clustering, these initial groupings could subconsciously influence how we thought about the data. This may have introduced bias into the data analysis process, which we explicitly acknowledge as a limitation of our work.

4.5 Reflexivity Statement

Two of the authors come from backgrounds experiencing noise sensitivity and/or encountering people in their family who have noise sensitivity, as people who are or may be neurodivergent. Our lived experiences and our positionality as researchers and system designers may shape the data collection process and interpretation of the findings. In our work, we apply a participatory design approach, through which we intentionally engage stakeholders in the iterative design and evaluation of technologies to understand their values, interests, and ideas for technology to support their needs. Engaging participants as co-designers rather than as simply tool evaluators or research subjects may engender feelings of "being on the same team" that could lead to more positive sentiments about the tool. We emphasized throughout the study that participants' roles were to critically evaluate the system and identify problems, and that critique was an essential part of the design process. During interviews, we asked open-ended questions and actively probed for negative experiences and limitations of the system. While we deliberately encouraged critical feedback and maintained reflexive awareness throughout the research process and analysis of the data, we acknowledge that our multiple roles may shape the outcome of this work.

5 FINDINGS

Decades of prior work indicate that self-awareness is supportive of self-regulation [32, 66] while awareness of challenges by others, especially allies and caregivers, can enable them to provide support [29, 30]. In this work, we aimed to understand whether and how assistive technologies might be designed to support all three types of awareness (*i.e.,* self, others, and joint awareness). Through a two-week field study, we deployed AudioBuddy as a technological probe to explore how the system design facilitates awareness of potential environmental stressors, such as loud noise, and the emotional and physical states of PWNS through the joint use[5] of the application. In particular, we examined how self-awareness for PWNS and others' awareness (*e.g.,* companions' awareness) is affected by AudioBuddy's data collection, reflection, and notification prompts. As we examine how AudioBuddy fostered awareness, we note that several of our key findings reveal fundamental constraints of consumer wearables that limit the system's effectiveness — particularly in sound detection capabilities — revealing gaps between participants' needs and current functionality. Thus, we explore these tensions throughout our findings and describe opportunities for improvement to better facilitate joint awareness for collaborative support.

5.1 Fostering Awareness Through Data-Driven Reflection

Joint use of AudioBuddy appeared to enable participants to engage in data-driven reflective practices throughout the study. During moments of reflection, participants considered their own and, in the case of companions, the PWNS' experiences. Reflecting on their personalized activity reports for the day enabled PWNS to visually identify changes in their environment and body, supporting awareness and understanding of their experience after being in a particular environment. For example, N1 realized that her "*heart rate really gets up there,*" which she saw as an indication that she was *"more stressed by [noise] than [she] thought [she] was."* Additionally, some participants mentioned never previously viewing their heart rate data; thus, using AudioBuddy provided insights into how their bodies responded in stressful conditions. To illustrate, N7 explained how having the graphs was "*interesting to look at, especially with the heart rate one, seeing [it] throughout the day.*" She further explained how she would look for "*when things went up and down"* to determine whether those were times when she was anxious or something else triggered the change in heart rate.

On the other hand, the noise graph may have helped companions be more aware of how loud some sounds and environments were and the impact on PWNS:

> *I decided to track the noise level because we are going to be in Disneyland, and there's going to be a lot of loud sounds. And so at the end of the day, going back and looking at that chart, I was like, 'Oh yeah, this is when we walked into that area that was like, super, super*

[5] PWNS and companions used the same app; however, they could not view or access each other's data.

noisy. And then this is where we walked into that area where it wasn't as noisy."' - C1

Companions shared that AudioBuddy helped them become more understanding and empathetic of PWNS' experiences. For example, N1 shared, *"Since using the app, I would say I have a little bit more grace for her when certain noises bother her."* From this, we see that such systems can help companions to be more reflective of the impact of environments on PWNS, and therefore more aware and empathetic to their experiences. These findings suggest that access to data and visualizations may enhance joint awareness of the impact that various environments and sounds may have on PWNS. By reflecting on the tracked data, either in the moment or at later periods, both PWNS and companions were able to identify events that contributed to or caused physiological and psychological changes.

Data can only be shared manually through generated reports, an area of critique for most companions (n = 8) who wanted the ability to "*passively view*" (N4) the PWNS' data for their own knowledge gathering and awareness. Particularly, they wanted to view the PWNS' mood data to understand their emotional state and provide support if needed.

> *"So whenever they input something, and they write down what's on your mind...I can see it from my app. And then if I'm somewhere, if separated, like, if she's at work and I'm at work, at least I can kind of see what's going on, and then maybe give a little check in."* - C2

Moreover, one PWNS, similarly, indicated not only wanting his mother to be able to see his mood data, but to be able to see hers as well.

> *"Maybe the ally's feelings can also be seen by the other person... So it's like, mama's feeling whatever... A BS meter, basically, how much BS you'll take before you get angry."* - N3

These findings suggest that the visibility of each other's emotional state can foster joint awareness. This joint awareness can then enable companions to determine whether the PWNS needs support, and help the PWNS understand the emotional state of their companion. This also suggests that we were perhaps overly cautious about data privacy concerns in our design.

Companions (n = 4) emphasized the need to view the PWNS data when they were not co-located, underscoring the value of facilitating awareness when PWNS and companions are not physically together. In other cases, some companions wanted to view PWNS data to identify the coping strategies that were most commonly used. Three companions (N4, C7, C8) were in this discovery stage of identifying strategies. Therefore, being able to view the PWNS data could inform companions of which strategies are being used, and they could recommend them during dysregulated moments. For instance, one companion shared:

> *"I can also see what she is routinely using as a coping mechanism. So that way I can see, oh, she's more inclined to listen to music, or she's more inclined to take a walk. Or she's more inclined to meditate. ... [T]hat might be helpful to me just as a caregiver in general, to say, 'Okay, when you have been in a loud environment, you've used this coping mechanism that has helped you. Right now, you're emotionally upset because of this. Why don't you try that same coping mechanism and see if that helps you?"'* - C7

Moreover, two companions wished to view their PWNS' data to support their own and others' awareness and knowledge gaining. For instance, one companion explained that she already keeps a journal to track her son's experiences, identify patterns, and share them with his counselor, so having the ability to view his data would be supplemental.

> *"I think I would be more interested in knowing [N5]'s data ... because I keep my own journal of when he's super dysregulated, because I want to see if there are patterns. ... I just want to record the things that he says so I could bring it up as a concern, if it's a pattern with his mental health counselor. I want to see, like, is it at certain times that he's dysregulated, or does it coincide with places where there was a lot of noise that day, or lack of a schedule."* - C5

Similarly, C3 shared that the data documented for her daughter could also be shared with her husband. These behaviors suggest that companions perceive viewing captured and tracked information on the PWNS as useful for their own awareness, as well as for the awareness of others who, to some degree, have vested interests in caring for the PWNS. This suggests that joint awareness of noise sensitivity may need to extend beyond a one-to-one model of support to a group with secondary caregivers and supporters who are aware of and can collaboratively manage noise sensitivity experiences and impacts on well-being.

Although participants wanted to share and access the PWNS data, they considered privacy concerns. In particular, companions often suggested that the PWNS should have control over who and when they can access their data. For example, C6 shared that access to the PWNS' data *"should not be a default,"* but they should *"give permission"* to the person they want to have access. Similarly, C5 expressed that she would want access if her son *"feels comfortable sharing"* his data with her and her husband. Her husband, C4, further explained:

> *"I don't want him to think that we're checking up on him, or that we're spying on his feelings, or, let's just say data for now. Whatever he puts there, I don't want him to think that, 'Okay, my parents are gonna see that', because maybe there [are] some things that he wants to keep to himself."* - C4

While companions valued the ability to have access to PWNS' data, they still considered the privacy implications of having access. Taken together, these findings reveal that joint awareness is not solely about providing access to data, but requires deliberate design choices about visibility, privacy, and the social dynamics of care. AudioBuddy successfully fostered awareness through data reflection, but our design choice to prioritize users' privacy and control of their data revealed a gap between participants' collaborative care needs and the system's capabilities. This gap highlights a conceptual tension of balancing user autonomy and privacy with collaborative care and disclosure.

5.2 Supporting Environmental Awareness Through Noise Alerts

Warning participants of increased noise levels through notification alerts supported their awareness of potentially problematic environments. Companions reported that when they received a noise notification, even though the environment was not noisy to them personally, it made them more mindful of their own exposure and whether certain environments would be too much for the PWNS. For example, C7 shared that using AudioBuddy made her *"more aware of noises,"* and inclined to ask herself questions like *"Is [N10] okay? Is this bothering her?"* Moreover, notifications often validated their experiences, showing that it was not just their *"personal sensitivity"* (N9). For example, PWNS mentioned occasions when they were in places that were loud to them and received a notification from AudioBuddy indicating that the noise was indeed loud, confirming their experiences:

> *"It actually helped me at home too, because I got home and my dad was playing music super loud, and it helped. I'm like, 'Okay, yeah, this is super loud.' ... I think it was, like, over 100."* - N6

Her mother (C3) further explained, *"It helped to prove her case that his music was loud."* This experience demonstrates how receiving noise alerts not only validates PWNS' experiences but can also raise awareness in others that a sound is problematic, thereby fostering joint awareness.

To better support their awareness of whether sounds or environments would be problematic for the PWNS, companions mentioned wanting to receive noise alerts when the environment exceeds the PWNS' threshold, rather than their own. In particular, participants envisioned real-time alerts indicating the PWNS is in a loud environment, while others envisioned being alerted if the person was exposed to problematic environments over a period of days. For instance, C5 shared:

> *"I think it should be set to what [N5's] noise decibel level tolerance is because there are times when we go somewhere and then we're saying it's not that loud...But then actual data will be, like, literally, it's the decibel level he says is uncomfortable...If we had actual feedback, of it's this many decibels, and then it notifies us, then it's kind of like, 'Oh, he's not overreacting.' I think that could be good feedback for us to respond accordingly."* - C5

These findings show that alerts of noisy environments can support self and joint awareness for PWNS and their companions, enabling them to self-advocate and validate what the PWNS is experiencing.

While some participants found it beneficial that AudioBuddy alerted them when their environment became loud, five participants mentioned this was less helpful because their noise sensitivity was not provoked by the loudness of sounds but by the context and characteristics of the sound. Thus, participants reported wishing that the app would identify specific sounds and characteristics of problematic sounds, beyond just the sound's volume. For example, N1 explained:

> *"My noise sensitivity isn't necessarily how loud it is, but the pitch, and I know the limitations of the study are that the Apple Watch can only record decibels, not actual pitch. I know [N2]'s noise sensitivity is chewing sounds and things like that, which don't tend to be very loud either. So I feel like if there was a way to gauge that we would find more value in the app."* - N1

Companions who were interested in understanding what sounds were problematic similarly critiqued the app's emphasis on loudness. For example, C6 explained, *"There are some sounds that I know bother him, but it's not based on how loud it is, so it's gonna be hard for the app to pick that up...because his noise sensitivity is not based on how loud it is."* C6 described wanting to identify specific sounds and patterns of sounds that bothered her son. This sentiment was shared by other companions like N4, who described sounds that bother her son that she does not notice.

> *"Sometimes he'll hear noises, and he'll say, 'Mom, do you hear that noise? Ugh, it's so annoying!' And I'm like, 'I didn't hear it.' I don't know what he's talking about."* - N4

These experiences highlight a limitation of the smart watch's noise-capturing functionality, which was the most commonly mentioned constraint that impacted people's perception of the usefulness of AudioBuddy in supporting their awareness regarding problematic sounds. This suggests that to support awareness and effective data capture and alerts regarding sounds, future systems should be able to detect a wider variety of sounds and characteristics that are problematic for PWNS.

5.3 Facilitating Awareness Through Mood Logging and Ally Notifications

Supporting emotional awareness may help people manage dysregulated emotions and increased stress, which are common in individuals with noise sensitivity. Therefore, AudioBuddy sent notifications for mood checks at the same time, four times a day. PWNS reported that periodically checking in with themselves helped them to better understand how they were feeling. For example, N2 shared that by using the app she had "*gotten to understand* [her] *mood better*" and "*understand more about how different situations can make [her] feel and how they can affect [her].*" Similarly, due to receiving the mood check-in notifications, N8 said "*it makes [her] pause and then try to see where [she's] at.*" Moreover, companions shared that it was good for them to check in with themselves, and for some (n = 4), doing the mood checks helped them be more receptive to how the PWNS was feeling.

> *"[The mood check-ins] will kind of force me to think about what I'm feeling ... And then when I'm going through that process, I will be like, 'Oh, well, I wonder how [N1's] doing, or I wonder how [N2's] doing', and then I will ... send them a little text message, 'Hey, just checking in. Is everything okay?'"'* - C2

Logging their own moods also led companions to remind the PWNS of their mood check-ins. This was particularly relevant during moments of dysregulation. To illustrate, C5 shared, *"[N5] was having big feelings, and [C4] goes, maybe right now is a good time to do a mood check-in. Put your mood check in."*

Moreover, during heightened dysregulated states, PWNS may need to access coping strategies to aid in emotion regulation. However, they may not be aware of what they can actually do to self-regulate, particularly when they are in vulnerable states [30, 40]. In such cases, participants reported that using AudioBuddy helped them to realize they had options for supporting themselves. In particular, AudioBuddy reminded participants of the coping mechanisms available to them when they felt overwhelmed and anxious. For example, N7 shared:

> *"AudioBuddy has helped make me more aware of what to do when I'm feeling a little overwhelmed. Like it kind of helped with seeing a visual of like, 'Oh, here are options you could do to help sort of distract and help you calm down from a potential sensory overload.' Whereas before, I kind of had a harder time, clearly thinking of what I could do to help. So the visual of the coping activities really helped with coping with sound sensitivity."* - N7

Additionally, participants shared that it was helpful when the app "*suggested coping mechanisms*" (N4) in response to the entry of a negative mood. Specifically, when participants logged moods in the "Not Okay" or "Bad" category, the app encouraged them to engage in a coping activity (see Section 3.3, Figure 1). This suggests that PWNS may need prompting throughout the day to support their awareness of their physical and emotional state and when they may need to engage in a coping strategy to regulate.

Moreover, in such cases, joint awareness is crucial, as having others who are aware (*e.g.,* a teacher, classroom aid, or friend) of noise sensitivity challenges may assist with regulating behaviors. For example, two participants (N2, N3) reported that having access to and using the coping activities was not as helpful for them when they were in school environments, in which they were not allowed to access their phones or watches. For example, N2 shared that during the school weeks are the most stressful times for her because "*noise bothers* [her] *a lot,*" but she "*can't really do anything at school if something goes on.*" Similarly, N3, who also has restricted access to devices in school settings, shared that often times at school he either has to "*avoid*" noises that bother him or "*push through.*" N1 had similar experiences where she would want to engage in a coping activity, but could not because she worked at a school.

> *"I just said that I'm gonna meditate, but then I wasn't really able to really isolate myself, but it at least reminded me just to breathe, you know, and then try to, like, [does deep breath] just do that, the breathing itself to kind of calm myself down."* - N1

These experiences reflect how PWNS often navigate overstimulating environments and may lack access to adequate resources for self-regulation or accommodations for their sensitivity, such as at school and work. This necessitates the importance of joint awareness to facilitate collaboration between the PWNS and other people to manage the experience together. Children with noise sensitivity spend much time in school environments, and having teachers who are aware of their experiences can help manage the environments by adapting the classroom to be minimally stimulating and engaging in co-regulation strategies with the child when necessary.

To support PWNS during dysregulated states, AudioBuddy featured a Notify Ally function (see Section 3.2, Figure 2) that enabled them to alert their companions when they needed help self-regulating. However, this feature was rarely used during our study, because PWNS either did not need it or were limited by environmental restrictions (*e.g.,* phone bans in schools or connectivity issues). For example, N7 shared that she did not need to alert her companion because she received support from someone who was with her.

> *"I didn't really need to send him the notification specifically, because I was in a situation where I could talk to someone that was with me that kind of already understood, not as much as he does, but like, I let my leads know that I have sound problems, and when I was having a hard time, I was like, 'Hey, can I go step in the stock room for a minute where it's quiet,' and they just say, 'Yeah go ahead.'"* - N7

Similarly, some PWNS were always with their companion, so when they encountered distressing situations, they simply told their companion rather than notifying them through the app. In other cases, participants reported that the notify ally message was "*dramatic*" (N1), sharing that it may cause their companions to think they were in a bad situation, when in reality they were updating them on their condition.

> *"That's scary. Just how it's worded. What if you're just trying to let someone know that you are alright? The way that it's worded will make them think you're not alright. If you're not okay, that wording is fine."* - N10

These findings point to the social dynamics of digital help-seeking. In particular, whether companions are physically present or not, a digital alert may feel socially awkward or excessive compared to simply speaking to their companion.

PWNS may not always be aware that they need support or are so dysregulated that they are unable to seek support. The Notify Ally feature assumes that the PWNS would recognize their need for support and have the cognitive capacity to navigate the app during dysregulated states. However, acute dysregulation may impact executive functioning and decision-making, making app navigation difficult when it is most needed. Relying on the PWNS in such moments to seek support can inhibit companions' awareness and ability to co-regulate and manage the situation with the PWNS. Companions requested automatic notifications in these cases instead of depending on the PWNS to send notifications. For example, C6 shared that for her son, she would want to *"be alerted if he's in a certain mood."*

These preferences reflect an important tension in our findings: systems designed for self-advocacy may inadvertently place a burden on the individuals using them. This finding challenges our initial design rationale and suggests that systems should incorporate gradual levels of automation. In particular, systems should incorporate escalation thresholds that move from PWNS-controlled sharing during stable periods to automatic alerts during detected dysregulation, while still preserving users' autonomy.

The effects of noise sensitivity can last well after the person encounters a problematic sound or environment. For example, when discussing her son's noise sensitivity, N8 shared:

> *"I didn't understand how long the effects could linger. I used to think, 'Just stay away from loud sounds, you'll be fine.' Now I see how it can affect him for the rest of the day."* - N8

In such cases, companions mentioned wanting to be aware if the PWNS is having recurring negative moods:

> *"But if I could be notified, if there's a streak of bad feelings, like, if there's three days in a row where my son is putting things down that are hard for him, then I would like to be able to be notified of that. Just be aware, like, 'Hey, maybe you need to check in with your son.'"* - C4

These suggestions indicate that companions envision systems that cultivate their awareness and understanding of PWNS' emotional states, ranging from immediate issues, such as dysregulated states caused by the environment, to more sustained experiences, including ongoing negative emotional states.

Participants' experiences using AudioBuddy highlight the opportunities and limitations of the system and consumer wearables for facilitating awareness of noise sensitivity experiences. While data reflection, alerts, and mood logging successfully fostered individual awareness, companion empathy and understanding, our findings reveal critical challenges. Current smartwatch devices cannot detect sound characteristics that trigger sensitivity experiences, manual data sharing limits collaborative care, and manually alerting allies can place burdens on dysregulated individuals. These limitations are not only technical challenges but also conceptual ones that reveal tensions between designing for user autonomy and collaborative care, privacy and necessary disclosure, and consumer device capabilities and the specialized needs of PWNS. In the next section, we discuss these tensions and opportunities for future systems to address them.

6 DISCUSSION

The results of our work indicate that mobile and wearable solutions are feasible for supporting PWNS' and companions' awareness of noise sensitivity experiences. We found that data-driven reflections facilitate awareness and understanding of the psychophysiological impacts of noise sensitivity, while also supporting awareness of noisy environments and their potential impact on PWNS. Mood tracking can enable greater emotional awareness, allowing participants to identify when they need to self-regulate. Participants' experiences also surfaced challenges and opportunities to further enhance joint awareness between PWNS and companions, which we discuss below and provide design recommendations for future systems to support awareness between PWNS and their companions (see Table 4).

6.1 Supporting Greater Joint Awareness

Joint use of AudioBuddy supported joint awareness through data-driven reflection and personalized noise alerts. Through tracking environmental noise levels and receiving alerts, PWNS and companions both reported identifying problematic environments and recognizing how these environments may affect PWNS. Having such data supported participants in achieving awareness of their noise sensitivity experiences and subsequent empathy from companions. These findings are consistent with prior work on personal informatics research, which emphasizes the value of data-driven reflection for awareness and behavior modification [17, 61].

In our current design, companions must rely on the PWNS to share their information, which can be challenging for companions who want to be more proactive or for PWNS who may struggle to share in moments of distress. While this supported self-reliance and independence for the PWNS [30], it also shifted the responsibility of reaching out for help onto the person experiencing a potential crisis and potentially limited the autonomy of companions. This design choice, therefore, tended to stifle joint awareness and opportunities for collaboratively managing experiences. This finding focuses our attention on the interdependent nature of these relations, in which PWNS and companions are mutually reliant on information sharing for joint awareness and collaborative support. A family informatics approach to system design [75] with PWNS-centric and companion-centric interactions could support joint awareness and foster collaborative management of noise sensitivity rooted in interdependence [5].

While participants expressed interests in viewing each other's data, such transparency introduces complex relational dynamics: tensions between privacy and autonomy, data-driven relational conflicts, and inducing burdens and anxiety. Continuous visibility of PWNS data to companions could create a sense of surveillance, restricting independence and leading to resistance behaviors, such as under-reporting moods. Additionally, such access to PWNS data may cause data-driven relational conflicts, where objective values, specifically regarding noise data, could lead to disagreements that invalidate PWNS' subjective experience. Moreover, constant access to PWNS data may lead to hypervigilance in companions, causing them to feel the need to constantly monitor and check in every time a negative mood is logged or the PWNS is exposed to problematic environments. C5's mention of wanting to track patterns about her son's experiences and share them with his counselor suggests companions may feel the need to have a comprehensive understanding and documentation of their loved one's experiences — a burden that could lead to caregiver burnout [96].

These concerns provide considerations that inform how future systems should be designed to better support joint awareness, while also preserving user privacy. Privacy-preserving approaches could include enabling **consent-based data sharing** (DI1) between PWNS and companions with configurable privacy settings, where PWNS control what data is visible and when (*e.g.,* sharing only when their personalized distress thresholds are exceeded), and **delaying visibility of data** (DI2), where companions see summaries rather than real-time data, reducing the feeling of surveillance, while maintaining awareness. Moreover, our study captured participants' interests in data sharing during a two-week period but did not observe long-term relational effects. Future research should examine how systems for joint awareness affect relational dynamics raised in this section over extended periods.

6.1.1 *Extending Joint Awareness to Secondary Supporters.*

Our findings also indicate that to support PWNS in managing their experiences, joint awareness of the person's noise sensitivity should extend beyond primary supporters. Having others who are aware

Table 4: Summary of Key Findings and Design Implications

Key Findings	Design Implications
Data reflection supported awareness, but companions want to view PWNS, which requires manual sharing.	DI1: Consent-based data sharing between PWNS and companions with configurable privacy sharing. DI2: Provide summarized, time-delayed reports to reduce feelings of surveillance and hypervigilance.
Joint awareness is needed beyond the primary caregiver, yet certain settings can restrict regulation approaches during distressed states.	DI3: Design situated interfaces for shared spaces that provide awareness, that support multi-stakeholder awareness, including teachers, coworkers, and peers.
Consumer wearables (e.g., smartwatches) cannot detect sound characteristics beyond volume.	DI4: Develop specialized sound recognition systems that identify and classify problematic sound types.

of their noise sensitivity, potential triggers, and ways to assist if needed, may be necessary to effectively support PWNS in various environments they encounter daily [29, 77, 80]. There is a need for systems that facilitate joint awareness between PWNS and stakeholders in such settings to support information sharing and collaboration.

The **design of situated interfaces that provide affect and ambient noise information** (DI3) can promote joint awareness of noise sensitivity experiences among PWNS and a variety of other individuals. Commonly raised settings of concern, such as schools and workplaces, could integrate such interfaces to support awareness of environmental noise and affective states of individuals in those environments. This approach could enable peers and those responsible (*e.g.,* managers in workplaces or teachers in classrooms) to support PWNS by adjusting the environment before dysregulation or other consequences. Prior research has investigated the use of situated interfaces to show noise level preferences in shared spaces [55] and relevant family affect information for awareness and reflection [87], and such systems have been in use in places like Neonatal Intensive Care Units, where patients have substantial sensitivity to noise for decades. Joint awareness can be stimulated by highlighting environmental data and affective states of individuals in the environment. For example, displays might depict the floor plan of the office or classroom with the sound level in the space, conveying the type of sound characteristics in the environment, similar to approaches applied with DHH people [47, 48], as well as the self-reported affective states of individuals in the environment. Information can be provided in real-time, allowing those in the environment to be aware when certain types and characteristics of sounds are detected that can become problematic, and how the environment is impacting the well-being of others. When a sound is detected or the overall ambient noise level exceeds a threshold, individuals in the environment can be notified that the sound or noise level may be bothersome to others and provided suggestions for improving the auditory environment, such as minimizing or removing the noise. Alternatively, more specific approaches could enable the person bothered by sounds in the environment to alert others in the workspace or directly to their teachers.

Each of these approaches has trade-offs. General notifications about the auditory environment, indicating elevated noises or that someone may be bothered by the noise, offer privacy for PWNS and can limit stigma, while encouraging joint awareness. However, this approach is less actionable in that it may not enable targeted help if needed. On the other hand, individual-specific alerts that show who is affected by the sound can enable others to be supportive, but this may be invasive and create unwanted attention that can reinforce stigmas. To balance these extremes, designers may consider a middle ground, such as depicting areas of concern without pointing out a specific individual. Default settings for the system may be to send general alerts broadly but allow individuals to share more specific information. Systems should be designed with different display modes for different contexts, such as more general in workplace settings or more specific information for classrooms.

The design of situated interfaces should facilitate awareness for support rather than producing the feeling of being surveilled. Continuous monitoring of the environment can raise privacy concerns, such as detecting and capturing intimate, sensitive conversations [48]. Therefore, designers may explore the application of inaudible sounds, which are privacy-preserving frequency bands for acoustic activity recognition [45, 95]. This approach can enable sound recognition to facilitate awareness of environmental sounds, while excluding speech and preserving the privacy of individuals in the environment. Affective information displayed could be summarized to reflect a general awareness of how the noise in the environment may be impacting individuals, rather than highlighting individuals' affective states. Importantly, this approach should not be confused with surveillance through emotion AI or similar approaches, through which individuals' states are automatically monitored [2, 79], as these approaches tend to be biased, inaccurate, and discriminatory [24, 52, 79], with little to no regulation to ensure privacy [18]. Instead, this information should be manually entered by the individual as a means of sharing information for greater joint awareness. Such approaches are what others have called privacy-compliant features [4], and may enable the facilitation of awareness while minimizing privacy and surveillance harms. Still, manual reporting brings challenges of its own, like requiring self-reporting during dysregulated moments, placing additional burdens on individuals who are already overwhelmed. Additionally, voluntary self-reporting may lead to underreporting if PWNS wish to avoid drawing attention to themselves or fear facing social consequences (*e.g.,* stigma, denied accommodations, etc.) [29, 80]. Future work should investigate how situated interfaces can effectively support joint awareness and collaborative care for noise sensitivity while incorporating controlled disclosure settings. This work should particularly examine their implementation in diverse environmental contexts and among various stakeholders to understand both the utility and feasibility.

6.1.2 Balancing Individual, Relational, and Structural Level Intervention. Overall, this work suggests that supporting PWNS and awareness requires consideration of multiple levels of intervention and that no single approach will adequately address the complexity of noise sensitivity experiences. Individualistic approaches prioritize self-awareness, personal coping, autonomy, and agency, yet they risk burdening the individual to consistently adapt or avoid environments that could be modified. On the other hand, purely structural approaches that only focus on environment modification may not account for the varied and personal nature of noise sensitivity, where one sound or environment that is intolerable for one PWNS is tolerable for another. Relational approaches that facilitate joint awareness between PWNS and their care networks are necessary when collaborative care is needed, such as during dysregulated moments. Future systems should be designed to consider which level(s) of intervention are most appropriate for different users and contexts, to create flexible systems that can support individual coping, enable collaborative support, and advocate for structural changes when necessary. These approaches are not competing solutions, but are complementary, enabling better support for PWNS' diverse needs and contexts.

6.2 The Challenge of Capturing Sounds for Awareness

The use of a smartwatch to capture ambient noise levels helped facilitate awareness of when environments exceeded participants' personalized thresholds. This customization supports PWNS who may perceive everyday sounds as excessively louder than people without noise sensitivity. Participants valued this personalization, validating their personal experiences and allowing them to make informed decisions. However, our design used commercial hardware that prohibited the capture and processing of some specific types of noises that were problematic for participants, and automatically assessing the specific characteristics that made them so challenging. These features had to do with the rhythm, pitch, or quality (timbre) of the sound, not its loudness [80, 94]. Customization of sound identification and tracking to meet these needs would be complex, as each person's noise sensitivity and the environments they encounter daily are unique. Moreover, sounds that may be perceived as problematic in one setting may be acceptable in another [77].

In light of these complexities, we see opportunities for wearable and mobile technologies that integrate **intelligent systems to capture and track problematic sounds** (DI4) for PWNS and their companions and facilitate awareness. Based on advancements in deep learning models for sound classification [37, 39, 74, 83], mobile and wearable AI-based sound recognition systems that process environmental audio can be used to support the detection of problematic sounds for both PWNS and their companions. Such approaches can enable PWNS to specify sounds that are problematic and, through audio signal processing, send notifications when these sounds are detected. Much like DHH research has indicated that these systems support sound awareness, allowing DHH people to have greater environmental awareness [8, 44], better sound recognition for PWNS and their companions can facilitate joint awareness of sounds that are problematic and environments that they may need to leave or adapt. Such approaches are effective for sounds that are above a certain decibel threshold, yet may prove challenging for detecting sounds that may not be registered by the microphones within current mobile and wearable devices. Designing sound recognition systems that can capture quiet sounds, such as lights buzzing or electricity in the wall, requires further research.

7 Conclusion

Our research demonstrates that assistive technology employing mobile and wearable systems can facilitate self-awareness, others' awareness, and joint awareness among PWNS and their companions for greater understanding of noise sensitivity experiences. Specifically, over the course of a multi-week deployment of a prototype system, data-driven reflection of environmental and psychophysiological contexts fostered awareness and greater understanding of how stimulants in environments can impact PWNS. In addition to reflecting on data collected, alerts for mood logging and increased noise levels supported awareness of affective states and when environments exceeded participants' personalized thresholds. Future work should consider how to capture a wide variety of problematic noises and the specific features that make them challenging. By collecting a detailed and comprehensive set of triggering sounds and environments, researchers could build intelligent models that generalize across the population and/or provide personalized support to individuals. Regardless of the underlying technical approach, novel systems in the future should support all three types of awareness tested here as well as expand joint awareness to a broader set of potential allies and supporters. A privacy-sensitive, personalized, and comprehensive approach to such assistive technologies could enable true collaborative management of sensory experiences.

Acknowledgments

We thank Luc Rieffel, Armando Beltrán, Arturo Morales Téllez, Ashhad Shah, Kohsuke Hirano, and Mahan Tafreshipour for their support in developing the AudioBuddy system. We thank the CHI Bootcamp at UCI for their feedback on drafts of the paper. This research is supported by the National Science Foundation Graduate Fellowship under Grant No. DGE-1839285 and support from the Jacobs Foundation CERES Network.

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