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Affordances for deaf and hard of hearing students' social participation in mainstream school environments

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ABSTRACT

As more deaf and hard of hearing (DHH) students attend mainstream schools, understanding how physical and social environments can support their social inclusion becomes increasingly critical. Limited access to informal, unstructured peer interactions like those occurring during recess – important contexts for developing a social life at school – is a key challenge.

This study makes three main contributions: (1) Synthesizing interdisciplinary research on DHH students' individual capabilities relevant to social participation through a narrative review, framed within school contexts using affordance theory. (2) Developing a novel affordance-based, conceptual framework that shows how DHH students' opportunities for social participation arise from dynamic interactions between capabilities and school environment. (3) Creating a practical tool to support school evaluation and intervention planning by stakeholders without extensive DHH experience, and guiding future DHH affordance research.

Findings demonstrate how DHH sensory, cognitive, and psychological capabilities interact with situational and environmental factors, including built spaces, group dynamics, and stigma. The framework also emphasizes how social experiences can, in turn, shape DHH capabilities over time. Supporting practical implementation, a DHH capability-environment matrix tool was developed, providing a visual means to map affordance relationships and systematically identify school barriers to social interaction.

By reframing DHH inclusion through an affordance lens, this work shifts focus from individual limitations to systemic and environmental contributors to exclusion, situating deafness within a broader spectrum of diversity. The paper concludes with implications for advancing affordance research in environmental psychology and outlines directions for further development and evaluation of the matrix in school settings.

1. Introduction

Deaf or Hard-of-Hearing (DHH) students often encounter limitations to social participation within mainstream schools, even though principles of educational equity require that all students have access to these essential opportunities for social development, being included and feeling welcome in their school community.

For many children and adolescents, daily life revolves around school, making this a key setting for social interactions. Here, the presence and quality of friendships and peer relationships can influence various aspects of development, including social well-being, school engagement and educational outcomes (Korkiamäki, 2016; Reeves, 2012; Robnett &

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Leaper, 2012). Most hearing[1] students can regularly socialize, build friendships, and engage in incidental learning (such as overhearing peer conversations) throughout the school day. However, these opportunities are often far less accessible to DHH students, which can contribute to feelings of exclusion and social disconnection, especially when peers are predominantly hearing (Netten et al., 2018).

According to the UN Convention on the Rights of Persons with Disabilities, all students have a right to a school environment that supports their social and academic development,[2] including students who are DHH. Today, most DHH students in the Global North attend mainstream schools, with over 60% in the Netherlands (van der Straaten et al., 2021), more than 70% in the US and UK (Consortium for Research into Deaf Education (CRIDE), 2019; Office of Research Support and International Affairs, 2014) and an over 80% in Australia (Punch & Hyde, 2010). In these mainstream educational settings, communication often relies primarily on auditory information, and barriers to accessing that information can make social interactions cognitively and emotionally demanding for DHH students. Such barriers result, in part, from inaccessible design of the built environment. Thus, while DHH students are often placed in mainstream schools under the framework of "inclusive education", e.g. in the US (Education for All Handicapped Children Act of 1975, 1975) or in The Netherlands (Appropriate Education Act, 2014), it seems that these school environments often fall short of providing the conditions necessary to optimally support a healthy development of *all* students, and especially social participation seems challenging.

This issue of access to social participation for DHH students can be framed through two perspectives. The medical perspective emphasizes treatments to align DHH youth's hearing abilities with those of their hearing peers. This perspective inherently frames deafness (also: "*hearing impairment*") as an individual dysfunction and key cause of exclusion. This places both the problem and its solution onto the DHH individual. Correspondingly, interventions like cochlear implants (CIs) and hearing aids (HAs) primarily aim to restore DHH individuals' ability to function in audistic[3] environments, i.e., spaces designed primarily around hearing people, by minimizing deafness.

In contrast, contemporary perspectives on inclusion emphasize the role of built and social environments in creating equal opportunities for all, regardless of (hearing) ability. The social model of disability, for example, interprets disability as the result of environments designed exclusively for able-bodied individuals – causing isolation and exclusion from full participation in society, *on top of* any impairments experienced by those who are not able-bodied (Campbell & Oliver, 1996; Leaman, 1981; Oliver, 1983; The Union of the Physically Impaired Against Segregation (UPIAS), 1976). From this perspective, hearing differences can be reframed as forms of "aural diversity" (Drever & Hugill, 2022) rather than dysfunctions. Thus, the problem is not in the DHH individual's capability, but in the mismatch between their wants or needs and the opportunities their environment affords. Social-environmental approaches focus on reducing this mismatch while preserving and valuing diversity. This shift reframes the issue from individual deficit to structural, cultural and interpersonal barriers that potentially disable people with bodily, neurological, or mental differences.

School environments consist of social, cultural,[4] and built (physical) layers, yet DHH research and interventions have yet to fully address these. To date, many DHH interventions primarily targeted the individual level – mirroring broader disability intervention landscapes (Koller & Stoddart, 2021) – as represented by the large body of research on hearing technologies, and early child interventions focused on language and communication training (Wright et al., 2021). More recently, the social environment of DHH students also started drawing attention, with research considering peer attitudes and behaviours and their role in shaping DHH students' inclusion (Eichengreen et al., 2025; Kent & Smith, 2006; Rieffe et al., 2018; Xie et al., 2014; Zaidman-Zait & Dotan, 2017). However, the third layer, the role of the built environment in shaping informal and unstructured social participation for DHH pupils with (mostly hearing) peers – e.g., by looking at spaces used for recess – remains significantly underexplored. This is despite clear evidence that design-related elements such as acoustics and ambient noise (both shaped by the built environment) affect in-classroom opportunities for complex peer interaction (McKellin et al., 2011) and have broad impacts on student learning and wellbeing across age groups and hearing profiles (Mealings, 2023; Minelli et al., 2022; Picard & Bradley, 2001). For DHH students in particular, inadequate sound environments often heavily affect their speech understanding, participation in the classroom (Choi et al., 2020; Iglehart, 2016, 2020; Nelson et al., 2020; Neuman et al., 2012), and school overall (Krijger et al., 2020); which also raises doubts about their understanding and participation outside the classroom, such as (often) noisy cafeterias.

To address the gap in research on how school *environments* can shape DHH students' engagement in unstructured social participation, and the resulting difficulty to systematically modify features of the environment to improve participation opportunities, this paper draws on the notion of affordances. Affordances, in short, are action possibilities emerging from the dynamic interaction between environment and individual (Gibson, 1979; Heft, 1989). They therefore lend themselves as a helpful theoretical tool to understand somebody's behaviour (such as social participation) and its outcomes not based on the individual's (dis-)abilities in isolation, but the way that these link with features of the environment. In a related context, previous research on schoolyard affordances has shown how built, social, and cultural features of school settings can either support or hinder peer engagement, depending on the child's affordances (Nasri et al., 2022).

In affordance theory, the set of an individual's physical, sensory, and cognitive competencies are often referred to as *action capabilities*[5] (Withagen et al., 2012). This concept is essential in applying affordance theory to the built environment, as it highlights the importance of alignment between environmental properties and users' ability to engage with them meaningfully (Koutamanis, 2025). Environmental availability, therefore, is not universal but relative: a space may support social participation for one student while remaining inaccessible or uninviting to another, depending on the students' diverse capabilities (Mohammadi & Koutamanis, 2025).

Building on this perspective, it is important to understand what constitutes an "available school environment" for DHH students (Rieffe et al., 2025), and how spatial and social design shape the interaction possibilities available to DHH students in everyday school life. To this end, we propose a conceptual framework to support interventions towards more inclusive school environments, aligned with international goals for educational equity and inclusion.

[1] In this paper, we refer to non-DHH or non-deaf individuals as "hearing", following current standards on non-biased terminology as suggested, e.g., by the Journal of Deaf Studies and Deaf Education.

[2] United Nations Department of Economic and Social Affairs: Social Development Issues/Disability/Article 24 – Education (United Nations, 2006).

[3] "Audistic" refers to the perspective that an individual is superior based on their hearing ability and related behavioural norms (Humphries, 1977).

[4] In this paper, the term school "culture" (as part of "social, cultural and physical layers") refers to broader norms, practices, and social expectations of a school — in this case, primarily shaped by the hearing majority, where spoken language is dominant.

[5] Sometimes also referred to as "effectivities" (Koutamanis, 2025).

1.1. Present study

In this study, we propose an affordance-based framework grounded in a narrative literature review to address: *How do different facets of the mainstream school environment shape social participation for DHH students?* We apply affordance theory to systematically examine and operationalize social participation as a relational process shaped by students' diverse capabilities and the possibilities for (inter)action provided by the environment. This approach links different individual DHH capabilities to concrete, modifiable, environmental conditions, conceptualizing the *availability* of a (mainstream) school environment in terms of the social interaction opportunities it affords each student relative to their capabilities. Using affordances also provides a shared language to align architects' and designers' perspectives with users' needs (Koutamanis, 2024). This enables targeted environmental adjustments, facilitating meaningful dialogue about how built learning environments are designed, understood, and utilized to support student participation (Young & Cleveland, 2022).

While Gibson's original affordance theory (1979) primarily emphasized physical action possibilities offered by a given environment, supporting social interactions of DHH students within that environment logically requires considering the role of other people, such as peers, as part of the affordance landscape. This broader perspective has been explored through 'social affordances', referring to the possibilities for interaction that emerge from the presence and actions of others (Lopes et al., 2018; Mohammadi et al. Forthcoming). Gaver (1996) further extended this view by arguing that social behaviour is inherently embedded in and shaped by the environmental context in which it occurs. This ecological perspective allows for the examination of how social actions and perception are guided by environmental affordances as arising from the dynamic interplay between built structures and co-present individuals (Mohammadi et al., 2017). Further, it is emphasized that such affordances are not only physical or material, but also situational and related to the user's capabilities and intentions (Koutamanis, 2025). This makes them highly relevant to inclusive school environments.

Affordance-based research has informed inclusive design in educational settings, with Young and Cleveland (2022) focusing on learning environments, Kyttä (2004) on child-friendly urban spaces, and Nasri et al. (2022) applying affordance theory and sensor-based methods to explore how schoolyard features shape peer interaction. While this research advances understanding of built environments and inclusion, it has yet to engage with the specific capabilities, needs, and experiences of DHH students. Relevant insights exist across audiology, psychology, and cognitive science, but remain fragmented, making it difficult to form a comprehensive understanding of how environmental design can support DHH students' social inclusion.

To move beyond isolated, discipline-specific interventions and toward an integrated framework that addresses the everyday ecosystem of school life, we employed a narrative review. This methodology is particularly suited to synthesizing diverse bodies of literature through a unifying lens like affordance theory. Narrative reviews allow for flexible yet rigorous engagement with complex, interdisciplinary topics and can support both theoretical development and practical application (Sukhera, 2022). As Lloyd and Gifford (2024) note in environmental psychology, narrative reviews are valuable for bridging disciplines, generating conceptual insights inductively, and amplifying context-sensitive, relational perspectives, all of which are relevant for applying affordance theory to the lived experiences of DHH students in school. Simultaneously, based on this narrative review, we developed a conceptual affordance-based framework and a DHH capability-environment matrix that identifies where and why typical barriers to social participation occur. By integrating interdisciplinary insights, this framework aims to guide environment-focused research and inform interventions promoting DHH inclusion in mainstream schools. We specifically focus on "mainstream" school environments, where DHH students are a minority among predominantly hearing peers and a school culture that is defined by this non-DHH majority. Spoken language is the dominant mode of communication, sign language knowledge is typically rare, and inclusion of DHH needs is not usually a high institutional priority, unlike specialized schools. By concentrating on these contexts, our framework aims to help diagnose barriers and guide practical adaptations in settings where DHH knowledge and awareness may be limited.

This paper advances environmental psychology and inclusive design research by:

- *Synthesizing fragmented knowledge:* Integrating interdisciplinary evidence on DHH students' capabilities through a narrative review, creating an accessible foundation for environmental and educational research.
- *Introducing a novel affordance-based framework*: Proposing a visual framework that newly applies affordance theory to DHH contexts, conceptualizing how DHH capabilities interact with school environmental features to shape social participation.
- *Providing an actionable capability-environment matrix*: Developing a practical tool to (1) support educators, designers, and researchers in evaluating and redesigning school environments for DHH inclusion, and (2) advance DHH affordance research in environmental psychology.

2. Materials and methods

A narrative review was conducted to synthesize current evidence on factors affecting DHH students' social participation in mainstream school settings. The review followed an iterative and selective process, starting from broad observations of DHH social participation (wherein links to external factors were often only implied) and then gradually identifying narrower questions about specific, underlying capabilities and contextual constraints that could be followed up individually. Initial literature searches used broad core search terms: "deaf and hard of hearing," "(mainstream OR inclusive) (school OR education)," and "social (participation OR inclusion OR interaction)". Subsequently, targeted searches addressed specific aspects of sensory, cognitive and psychological capabilities ("listening fatigue," "directional hearing," "auditory processing," "pitch perception," "speech in noise understanding," and "cochlear implants") and environmental factors affecting DHH experiences (e.g., "deaf architecture" and "(noise OR acoustics OR sound environment) AND (deaf OR hard of hearing),"), ultimately drawing from a broad range of academic literature.

Articles were included based on their relevance to emerging sub-questions and the contribution they made to understanding DHH social participation in the mainstream context. Peer-reviewed journal articles were prioritized, with a limited number of reputable alternative sources (official design documents, technology manufacturer websites, scholarly books and encyclopaedia entries) included where necessary. In total, 104 sources were included, of which 93 were peer-reviewed. Most sources were located via Web of Science and Google Scholar, supplemented by references from relevant papers. Details on the overall procedure and the included literature per narrative sub-theme (these correspond to the structure of the result section and the resulting, proposed framework) is visually summarized in Appendix A (Figure A.1).

For the affordance-based framework, we followed Borg et al. (2008), who defined a framework as a set of clearly defined and interrelated concepts that have not yet been structured for quantitative testing. At present, research on affordances for DHH students is not sufficiently developed to support predictive modelling of relationships between individual capabilities and environmental features, which this study aims to help advance.

3. Results

Based on the narrative review, we here present an affordance-based framework for examining and supporting social participation among DHH students in mainstream school environments (see Fig. 1). Grounded in a structured synthesis of existing literature, the framework illustrates how environmental and situational features interact with individual action capabilities to shape available social affordances. It connects research on DHH students' capabilities, contexts, and lived experiences through a relational perspective on affordances.

3.1. *Situated Social Setting: understanding the situational context of DHH social interactions in mainstream school*

The first element of the affordance-based framework (Fig. 1, left) comprises the "Situated Social Setting", which describes the conditions under which social interaction occurs. In addition to relatively stable "Environment Properties" (built, social, and cultural), we explicitly highlight the more dynamic, context-specific aspects of "Social Activity/ Situation Properties" that interact continuously with these stable elements. This is explored by examining common settings relevant to DHH students, focusing on how environmental and situational features interact to shape opportunities for social participation in section.

A typical school day comprises a range of formal and informal social situations, each affording different types and levels of participation. These interactions involve active engagement in conversations, friendships, and conflicts, as well as passive learning through observing or overhearing others (Rieffe et al., 2018). However, the extent to which participation is possible depends on the type of interaction and the social, cultural and built environment, which together establish implicit expectations regarding students' capabilities.

For DHH students, the situational contexts of social interaction in school often present substantial barriers to meaningful participation, referred to as 'social deafness' (Michael et al., 2019; Punch & Hyde, 2011). While many DHH students enter mainstream education with speech and language abilities seemingly on par with their hearing peers, this assumption is typically based on observations assessed in controlled, structured, quiet environments (Tsach & Most, 2016; A. M. Vermeulen et al., 2007). As a result, these apparently high auditory skills are not always representative for complex, real-world communicative settings. In noisy group conversations DHH students frequently struggle to initiate and sustain interactions (L. E. Paatsch & Toe, 2014; Zaidman--Zait & Most, 2020). As group size, background noise, and the complexity of social dynamics increase, so does the likelihood of communication breakdowns (Xie et al., 2014). As a result, DHH students in mainstream schools are often excluded from social peer interactions (Vermeulen et al., 2012).

The environment conditions that result in social deafness for many DHH students are pervasive across school settings where social interaction with peers typically occur (Busch et al., 2017). DHH students report experiencing barriers to participation during group work, engaging in conversations with peers and interacting in large reverberant spaces like gyms and social areas like school cafeteria (Krijger et al., 2020), or in noisy outdoor settings (Preisler et al., 2005) – often due to a combination of architectural design, ambient noise, and unstructured peer interaction.

However, peer interaction itself takes different forms depending on the context. Broadly, interactions in school can be grouped into three settings. First, a significant portion of time is spent in classrooms, where, besides formal teaching, students may interact with peers during group work, through exchanges with seat neighbours, or overhearing others chatting before and after lessons. Second, beyond the classroom, informal interactions occur during breaks, where school policies may influence where students are allowed to spend their time (Rieffe et al., 2024). Frequently, breaks are spent in spaces like school cafeterias, where students tend to gather in groups for extended periods. Third, interactions happen when navigating the school building, going from one class to the other, in transitional spaces like hallways. Here, interactions are typically brief, spontaneous exchanges. We explore two of these situational contexts in more detail.

School cafeterias typically consist of large spaces with group seating, enabling multiple simultaneous conversations in proximity. Affordances in such spaces are shaped both by the built environment and by the social behaviour of students within it. The ambient noise levels, largely generated by human speech, increase non-linearly due to the Lombard effect: in noisy environments, people increase their voice level and their pitch, and they tend to lengthen word duration to stay intelligible on the background of interfering noise (Brumm & Zollinger, 2011; J. Luo et al., 2018). The result is a complex acoustic environment where students perceive overlapping speech streams, with each stream being

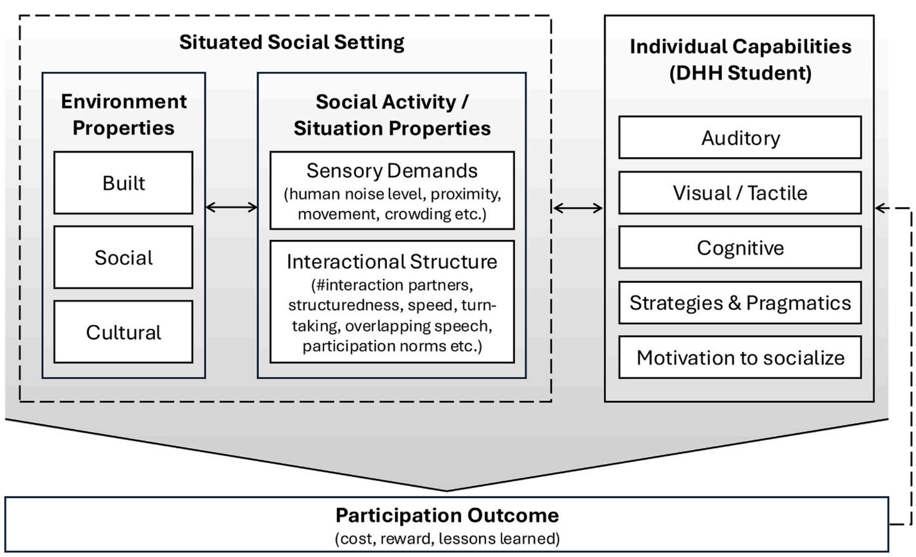

Fig. 1. Affordance-based framework for examining and supporting social participation among DHH students in mainstream school environments. This diagram shows how social participation outcomes result from the relation between aspects of situated social setting (left box, wherein fixed environment properties and social activities/situation properties may interact dynamically) and DHH students' individual capabilities (right box). Participation outcomes again feed back into the individual's future capabilities.

characterized by a different proximity and clarity. Successfully engaging in conversations under these conditions requires not only basic hearing capability, but the ability to focus on one speaker amidst background noise like traffic or chatter – also called "cocktail-party problem" or "cocktail-party effect" (Augoyard, 2005; Broadbent, 1958; Cherry, 1953).

Transitional spaces such as hallways present a different but equally demanding set of conditions for social interaction. These environments primarily afford short, spontaneous interactions that occur while students are in transit, e.g., between classrooms. Communication in this context often lacks visual contact with the interaction partners, as students do not necessarily stop to face each other while speaking. Due to the transitional nature, background noise in these spaces is not static but moving, adding another challenging component to auditory perception.

3.2. Individual action capabilities of DHH students in context

The second element of the affordance-based framework (Fig. 1, right) comprises DHH students' "Individual Capabilities", referring to the personal resources they bring to a social setting. These include sensory capacities (here: auditory, visual, tactile), cognitive abilities, behavioural resources (strategies and pragmatic skills), and psycho-social factors such as motivation to engage with others. Affordances emerge from the interaction between these capabilities and the context for participation ("Situated Social Setting"). Importantly, a "Participation Outcome" (Fig. 1, bottom) feeds back into individual capabilities, as social experiences can influence perception, strategy use, expectations, and motivation, shaping how future affordances are recognized and acted upon. Action capabilities, and how they act and evolve in the present context are central to the proposed framework.

To explain why typical unstructured and dynamic social interactions in mainstream schools can be challenging for DHH students, and to clarify the rationale behind the inclusion of each capability in the framework diagram, the following sections provide deeper insight into DHH auditory capabilities (3.2.1), visual and tactile capabilities (3.2.2), and cognitive, behavioural and psycho-social dimensions – focusing on the interplay between cognitive resources, pragmatic skills and strategies, and motivational aspects (3.2.3). For each capability category, we include a table that interprets relevant literature in relation to situated social contexts, drawing a direct link to affordances for social participation. These tables serve as an intermediate step toward a final matrix, which visually summarizes and connects the key factors discussed throughout the paper (3.3., Fig. 2).

3.2.1. Auditory capabilities

Auditory affordances, being action opportunities shaped by sound, depend heavily on a person's hearing ability (Noble, 1983). In mainstream (school) settings, social interaction primarily relies on spoken communication and, generally, full access to sound is often assumed from all its inhabitants. Typically, auditory perception enables rapid, 360-degree access to environmental and social cues, since sound travels quickly and does not require a direct line of sight. This allows individuals to locate, interpret, and respond to speech and environmental signals with minimal engagement (O'Callaghan, 2021), an advantage that is reduced when auditory access is limited. Thus, beyond supporting speech, auditory perception helps individuals notice others' presence, respond to conversational cues, and orient themselves in shared spaces. It also conveys ambient information (like room size, activity, or mood) without requiring visual focus. Limitations in hearing result in reduced access to these cues, hindering social awareness and participation unless

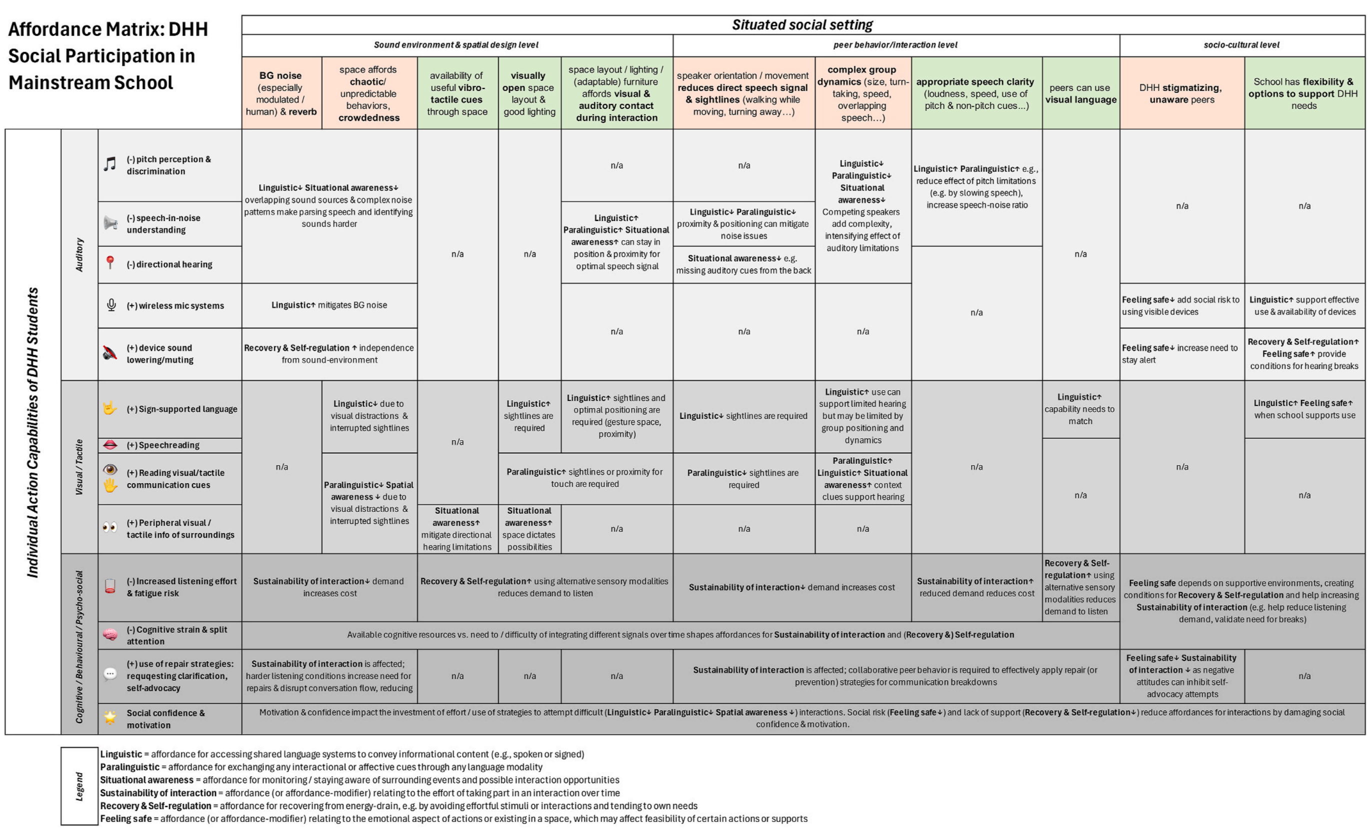

Fig. 2. Matrix of DHH Capabilities and School Environmental-Situational Features to help Identifying Opportunities and Barriers to DHH Social Participation in Mainstream Schools. This matrix connects DHH capabilities (rows) with environmental and situational features (columns) identifying different types of "intersections" as described in the legend. Column headers tinted red indicate a negatively formulated environment aspect, green tint a positive formulation. An interactive and more user-friendly version of the matrix (including lay terminology in the legend) may be accessed via: OSF repository affordance matrix.(For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

compensated for (e.g., using visual information; see section 3.2.2).

While DHH students' auditory profiles vary both quantitatively (e.g. level of hearing loss) and qualitatively (e.g. access to different auditory cues), the following sub-sections outline key aspects of their auditory capabilities in the context of mainstream school social settings (see Table 1). This section therefore aims to explain why many DHH students, despite strong spoken communication skills in ideal conditions like one-on-one conversations in quiet (Tsach & Most, 2016), often struggle with everyday interactions involving noise, multiple speakers, and busy classrooms.

Baseline Speech Perception, Pitch Perception and Discrimination. The availability of various auditory cues in the speech signal is, fundamentally, the basis for effective verbal and para-verbal (not speech, but contextual information resulting from voice) communication. For many DHH students, some of these cues may not be readily available through hearing alone, due to limitations in hearing thresholds and pitch perception.

Auditory perception varies among DHH individuals, especially in terms of pure-tone hearing thresholds (minimal detectable sound level) that are depicted in audiograms. Based on these audiological measurements, hearing loss can be classified into a range from mild to profound deafness. Many DHH students in inclusive settings use HAs or CIs (van der Straaten et al., 2021) to improve access to verbal communication. For instance, CIs (a common technology that utilizes computer-based processing to directly stimulate the auditory nerve and restore speech perception (Wilson & Dorman, 2008)) also allow DHH students with severe or profound deafness to access mainstream education (Bae et al., 2019). However, these devices do not fully restore typical hearing, and their benefit depends on various individual demographic and clinical factors like age at implantation, residual hearing, and education (Stronks et al., 2025) and user adaptation.

Speech perception also depends on pitch sensitivity, as individuals' hearing thresholds typically vary across different pitches. DHH listeners often struggle with high-frequency sounds like consonants more than low-frequency vowels, particularly in noise (Subramaniam & Alur, 2006). This has direct implications for speech understanding and social interaction, since consonants often carry crucial meaning within a language. For CI users, limited spectral resolution further affects access to pitch cues (Oxenham, 2008; Stickney et al., 2007; Wilson & Dorman, 2008), which can impair speech clarity and the perception of prosodic information (a key part of paralinguistics that conveys meaning beyond words) like emotional tone (X. Luo et al., 2007; Pralus et al., 2021; von Eiff et al., 2022), speaker intent (Rothermich et al., 2022), and limit understanding in tonal languages (Wei et al., 2007). In scenarios with multiple speakers, it is also harder to distinguish them when voices have similar acoustic features, such as same-gender speakers (Li et al., 2022). To compensate, DHH individuals may rely more on non-pitch cues like intensity, tempo, duration (Jiam et al., 2017; Wei et al., 2007), and timbre (von Eiff et al., 2022).

Cocktail party problem: separating speech from background noise. In acoustically challenging spaces like cafeterias, where multiple conversations occur at once, DHH students face difficulties separating target speech from surrounding noise. This builds on the previously mentioned cocktail party problem, which involves isolating a single voice amid competing speech signals. While hearing individuals can rely on fine-grained pitch and directional information to perceptually separate overlapping or competing sounds (i.e., auditory stream segregation) and filter speech from background noise, DHH individuals often have limited access to these cues (Iglehart, 2016; Neuman et al., 2012; Stronks et al., 2020).

CI users in particular are affected by how their processors encode sound. For example, they often cannot benefit from "release from masking", which helps hearing individuals recognize speech during natural dips in fluctuating noise like background chatter (Croghan & Smith, 2018; Eichenauer et al., 2021). Instead, CI users tend to perform better in steady-state noise, but often struggle with fluctuating noise or overlapping speech streams, where changes in intensity and competing voices make speech perception more difficult (Li et al., 2022; Stickney et al., 2007; Stronks et al., 2020).

Directional hearing challenges. These speech-in-noise challenges are further complicated by limitations in directional hearing. Spatial cues help the brain group together sounds coming from the same location while separating those coming from different directions. Beyond supporting speech-in-noise understanding, directional hearing is crucial for staying aware of surroundings, locating sound sources (e.g., peers speaking) and appropriately responding to social cues. It enables a person to turn when called from behind or remain engaged in conversation without constantly shifting attention to scan the environment.

However, for many DHH individuals directional hearing is limited (Zheng et al., 2022) – especially for those with asymmetric hearing loss, due to the absence of interaural (between-ear) time and level differences. A notable population with asymmetric hearing loss are those with single-sided deafness and unilaterally implanted CI users. While bilateral hearing solutions such as bimodal (CI + HA) and bilateral CI fittings can improve spatial hearing (Baron et al., 2019; Lee et al., 2022; Steffens et al., 2008), they rarely support the spatial acuity to the level of hearing individuals. When sound sources are close together they can be hard to differentiate for DHH listeners (Chan et al., 2008; Lee et al., 2022). DHH students whose spatial hearing is limited may miss subtle auditory cues, orient too late, or depend more on visual strategies to monitor their surroundings, which can disrupt the flow of social interaction. Environments can aid effective compensation by supporting the use of these non-auditory strategies (see 3.2.2).

Processing of sound by speech processors integrated in hearing devices, such as HAs and CIs can further complicate directional hearing. For instance, a commonly used front-end processing approach to improve speech-in-noise are directional microphones (beamformers) (Langerak et al., 2024; Stronks et al., 2022). Directional microphones are spatial filters and enhance the signal from a particular direction and suppress competing noise. The effectiveness depends heavily on stable speaker positioning and is often reduced in dynamic, multi-speaker settings. Moreover, because they generally operate by transmitting sounds from the front and suppressing those originating laterally and from the back, beamformers potentially disrupt any remaining spatial cues available to the listener.

Interaction between auditory capability and acoustics of a space. The acoustic quality of the environment plays a crucial role in DHH students' ability to engage socially at school, and poor acoustic conditions can significantly limit their participation (Haukedal et al., 2018). Key social spaces such as cafeterias, hallways, and classrooms are often affected by reverberation, a central feature of indoor acoustics. Reverberation refers to the persistence of sound after the source has stopped, and reverberation time describes the duration required for the reverberant signal to decay below a certain threshold.

For students with CIs, reverberation can significantly reduce speech understanding (Badajoz-Davila et al., 2020; Eurich et al., 2019; Hazrati & Loizou, 2012; Iglehart, 2016; Kressner et al., 2018), as sound waves bounce off room surfaces (sound reflections) and blur the original speech signal, making it harder to decode. CI users who perform comparably to hearing peers in quiet conditions often experience steep drops in comprehension in noisy or reverberant settings, sometimes understanding only 25 percent of what their peers do (Espino et al., 2006; Iglehart, 2004). While typical students benefit from reducing reverberation times to below 0.6 s, students using CIs often need reverberation times below 0.3 s for there to be a noticeable improvement in speech understanding (Iglehart, 2016; Neuman et al., 2012). Speech clarity improves when reflections are minimized and the speaker is physically closer, increasing the proportion of direct to reverberant sound (Badajoz-Davila et al., 2020; Eurich et al., 2019; Kressner et al., 2018). More recent studies confirm that reverberation not only hinders speech perception but also worsens subjective listening experiences (Langerak et al., 2025). Together, these findings highlight the importance of thoughtful acoustic design in school environments to support effective communication for DHH students, particularly those with CIs, who are especially vulnerable to reverberation.

Extending auditory capabilities with technology. Various assistive technologies used by DHH students can extend auditory capabilities, sometimes even in ways that differ from or exceed those of their hearing peers. One widely used approach involves personal remote microphone systems,[6] which improve listening conditions in formal educational settings by transmitting the speaker's voice directly to the listener, thus enhancing the clarity of the target speaker in noisy classrooms (Choi et al., 2020; Espino et al., 2006; Vermeulen et al., 2007). However, such systems are less effective in informal or dynamic social situations, where spontaneous interactions, multiple speakers, and fluctuating environments limit their utility. Furthermore, the presence of such technologies does not ensure their effective use. As Krijger et al. (2020) note, teachers and communication partners often fail to use the technology correctly. For instance, interaction partners sometimes fail to speak directly into the designated microphone, which undermines any potential benefits.

CIs are also continuously undergoing significant technological developments, particularly in signal processing strategies designed to improve speech perception in complex, real-world acoustic environments (Fischer et al., 2021; Lemercier et al., 2022, pp. 171–175; Xu et al., 2020). Recent developments with CIs have resulted in sound processing algorithms that allow for speech enhancement in noise when the speech is coming from specific directions, which helps users follow conversations in noisy settings, particularly when combined with a hearing aid in the opposite ear (Langerak et al., 2024). Other approaches leverage spatial cues captured by CI microphones to better separate speech from background sounds in complex environments (Olalere et al., 2025). In addition, new dereverberation algorithms could reduce the impact of reflected sound in reverberant rooms (Langerak et al., 2025). Still, individual outcomes with CIs vary widely and are influenced by several factors, including the duration of unaided hearing loss and the age at implantation (Blamey et al., 2013; Stronks et al., 2025). Earlier implantation, particularly bilateral, has been associated with more favourable outcomes in speech and language development and more efficient integration of auditory signals, often resulting in reduced listening effort (Boons et al., 2012; Ehlers et al., 2017; Steel et al., 2015). With increasingly widespread newborn hearing screenings and early intervention programs, recent cohorts of DHH students with CIs are likely to present different profiles in terms of auditory capabilities compared to earlier generations (De Raeve et al., 2012; Hoffman et al., 2016).

While modern CIs are primarily designed to support access to speech, they also offer features that extend beyond the capabilities of typical hearing. For example, CIs can integrate directly with digital technology, connect to smartphones, tablets or other devices via Bluetooth,[7] bypassing environmental sounds entirely. Relevant for social situations, many CIs (and HAs) offer programs and settings[8] to prioritize certain sounds or filter out others, making it possible to customize the auditory experience and adapt it to different social contexts (Kliesch et al., 2024). This includes lowering or muting environmental sound input, letting students manage energy or sensory comfort through listening breaks, though this possibility depends on whether students feel comfortable doing so at school (Klein et al., 2024). For example, "switching off" hearing may lead others to wrongly assume rudeness when a student does not respond, since CIs being inactive is neither visible nor expected – highlighting the need for an accommodating and well-informed school environment.

Affordance implications and possible facilitation. DHH students' auditory capability profiles can reduce participation affordances in crowded or noisy settings, where background noise, competing talkers, and unpredictable group dynamics disrupt verbal and paralinguistic communication as well as situational awareness. By deconstructing what is typically a subconscious hearing process, we highlight aspects that differ for DHH students, including limited directional hearing and the strong influence of room acoustics on auditory access. Interaction affordances can be increased by designing spaces that reduce crowding, noise (including cross-contamination between spaces), and reverberation; by enabling DHH students to position themselves at auditory vantage points that minimize missed auditory or visual cues; and by supporting interaction practices such as close, face-to-face positioning, turn-based talking strategies, and speaking articulated and at an appropriate pace. Schools can further enhance affordances by designing spaces and activities with contemporary assistive technologies in mind, supporting and normalizing the use of up-to-date wireless microphone systems across classroom and social spaces, while accounting for how different hearing devices shape access to, or exclusion from, the sound environment.

3.2.2. *Visual/tactile capabilities*

To compensate for limited availability of auditory information, many DHH individuals use other sensory (Blacutt & Roche, 2020) and communication modalities (Adami & Swanwick, 2019) to enhance their social participation in mainstream, hearing environments (see Table 2). In the (American) "DeafWorld", Rosen (2012) describes three primary sensory orientations that DHH people use to engage with the world: visual, auditory and tactile. The way each DHH person prioritizes these sensory modes varies.

Most DHH students in mainstream settings rely heavily on hearing, and may not need (or even know) sign language. However, some students benefit from sign-supported language (Knoors & Marschark, 2012). In some countries, DHH children in inclusive settings have the right to receive government support to ensure equitable learning opportunities (following the UN convention), including some level of visual language support. However, this is not necessarily implemented effectively or uniformly across schools, also because the lack of sign-language abilities across students and staff limit the general usefulness of using a visual language (Holmström & Schönström, 2017). Still, for those familiar with visual languages, having the opportunity to use sign-supported spoken language ("cued speech") in combination with speechreading can be extremely important to support speech perception in difficult listening conditions (Bayard et al., 2019) and offering relief from the demands of hearing. Even without full fluency in a visual language, DHH students may still focus on visual cues such as body language or facial expressions from interaction partners. These cues are helpful to gather contextual information (e.g. paralinguistic), and compensate for missing auditory input, supporting their navigation of social situations (Tsou et al., 2021). In particularly challenging auditory environments, many DHH individuals rely on maintaining a clear line of sight to the speaker to combine lip-reading with hearing. At the same time, peripheral vision serves as a key basis for spatial awareness, e.g. see the DeafSpace framework (Bauman, 2010), which help compensating for missing directional auditory cues and limited auditory scene analysis.

While DHH individuals may develop action capabilities to effectively gather and integrate information from multiple sensory modalities, this adaptability relies on whether environments support such strategies and facilitate the use of various cues. The structural design of the school environment is critical in this regard, particularly in terms of proxemics, i.e. how space and distance between speakers affect communication (Hans & Hans, 2015). Overall, an environment that enhances DHH students' sensory reach through vision, vibration, and tactile cues can create a "360-degree" sensory experience, increasing affordances for

[6] E.g., the *Roger™ wireless hearing aid microphones* (Phonak, 2025).

[7] E.g., the Advanced Bionics "Naída" Speech Processor was among the first to enable Bluetooth compatibility across both Apple and Android platforms (Advanced, 2025).

[8] E.g., AutoSense OS™ 3.0 (Advanced Bionics, 2022).

social participation. For example, floor vibrations can signal nearby movement, while well-designed reflective surfaces can extend the visual field and make others' presence noticeable without auditory input. In contrast, poor lighting, glare, and high contrast can make communication challenging and tiring (Bauman, 2010). When multiple barriers combine, like a dark space without visuals in combination with background noise (Rich et al., 2013), this diminishes opportunities to gather sufficient information to participate in an interaction (Krijger et al., 2020).

Affordance implications and possible facilitation. Visual and tactile affordances play a central role in social interaction for DHH students, making sightlines, lighting, and spatial layout critical to whether non-auditory information can be effectively used across different modes of interaction. Building design and activity planning should therefore aim to support unobstructed visual access to faces, gestures, and contextual cues. On a case-by-case basis, hybrid or fully visual communication strategies may be beneficial by building on DHH students' strengths, but their effectiveness depends on adoption at a broader social-cultural level rather than isolated individual use. Facilitation does not necessarily require formal sign language instruction but can involve raising awareness of alternative or supplementary communication strategies, particularly in noisy environments or situations where auditory devices are unavailable or impractical.

3.2.3. Cognitive, behavioural and psycho-social dimensions of DHH social participation

*We hear with the brain, not the ears (adapted from "We see with the brain, not the eyes" (*Bach-y-Rita, 1972*)). "When and how much effort we expend during listening in everyday life depends on our motivation to achieve goals and attain rewards of personal and/or social value." (*Pichora-Fuller et al., 2016*, p. 6S).*

Social participation in hearing environments depends heavily on the ability to listen to others, where "listening" refers to hearing with intention and attention (Kiessling et al., 2003) and involves both auditory and cognitive processing. For DHH individuals, fragmented or inconsistent access to auditory input increases cognitive demands, influencing how they can and are willing to engage in effortful interactions (Edwards, 2016; Pichora-Fuller et al., 2016), e.g. in a noisy school cafeteria. The following sections examine how listening effort, fatigue, motivation, and pragmatic strategies contribute to social affordances (summarized in Table 3).

Listening effort, allocating cognitive resources & fatigue. While daily listening is often automatic and effortless for hearing students, DHH students often find it energy-consuming (Dammeyer et al., 2018). Many DHH individuals report that even when speech is understood clearly, listening can remain tiring and difficult, highlighting the distinction between speech recognition and effort (Pichora-Fuller et al., 2016).

The FUEL framework (Pichora-Fuller et al., 2016) adopts Kahneman's definition of effort (1973), conceptualizing listening effort as the deliberate allocation of mental resources to overcome listening challenges. Effort varies not only with the difficulty of the task (demand) but also with the motivation to engage. Available cognitive capacity can be allocated to the task either automatically, such as when attention is drawn to a sudden stimulus, or consciously, like focusing on a challenging conversation. However, when perceived listening costs outweigh the benefits or one's "energy tank" is depleted, e.g., after a long school day, DHH students may disengage instead of investing effort in listening.

In FUEL, cognitive capacity is influenced by "input-related demands", which may be modified to reduce listening effort. These demands are influenced by various factors, which mirror concepts already included in our affordance-based framework: factors related to source (speech signal properties), transmission (distortions from auditory devices like cochlear implants or room acoustics), listener (auditory capabilities), message (listener's context knowledge, such as vocabulary), and context (visual cues and predictability of social dynamics). Edwards (2016) notes that environmental noise and other auditory distortions increase the complexity and cognitive load of speech understanding. As interpreting speech becomes more challenging, DHH listeners depend more on effortful, top-down processing, for instance by filling in missed words retrospectively based on conversational context ('postdiction'), which critically relies on working memory (Winn, 2024). Thus, following speech, potentially even while simultaneously analysing the auditory scene for context, is cognitively demanding for DHH students in everyday social situations. Participation challenges must therefore be understood not only in terms of the auditory signal but also in relation to factors that affect the ease of navigating interaction dynamics, managing distractions, and sustaining attention.

Frequent exposure to cognitively demanding listening situations (especially when sustained or unmanaged) has been linked to listening-related fatigue, a common issue among DHH individuals that often reduces the willingness and capacity to engage in socially challenging contexts (Bess et al., 2020; Davis et al., 2021; Hornsby et al., 2024). For example, fatigued DHH students may begin to avoid otherwise manageable group settings in favour of lower-effort interactions (Leigh et al., 2009; Zaidman-Zait & Dotan, 2017). Hence, the social affordances available to them shift depending on whether they are experiencing listening-related fatigue.

Risks for listening-related fatigue increase under persistently poor acoustic conditions, reduced attentional capacity (Bess et al., 2020), large mismatches between DHH students' motivation to listen and their available energy, or limited access to recovery strategies (e.g., listening breaks) (Davis et al., 2021). CI users may, on average, experience less listening-related fatigue than individuals using HAs, possibly due to more intensive therapy and support during post-surgical rehabilitation[9] (Feenstra et al., 2025). However, neither speech understanding ability nor severity of hearing loss consistently predict listening effort or fatigue risk. Instead, listening-related fatigue appears to depend more on subjective experiences of disability (Hornsby et al., 2024). For DHH students with CIs, improved speech perception does not eliminate cognitive strain and high listening effort remains a concern, especially in noisy settings (Finke et al., 2016). Pressure to meet expectations around CI performance can further interfere with wellbeing (Holman et al., 2021), e.g. by ignoring exhaustion in favour of fitting in with hearing peers. This highlights the importance of environments that not only reduce acoustic barriers, but also the psychological cost of participation by supporting recovery strategies and normalizing their use.

Strategies to manage social interaction and pragmatic skills. Managing barriers to daily social interactions requires adaptive behaviours that enable DHH students to remain engaged despite communication breakdowns and the cognitive demands of difficult listening situations. Social interactions involve more than perceiving speech; they are dynamic and governed by implicit social rules. Successful participation depends on pragmatic competence, a set of skills essential for initiating and maintaining fluent conversations (Tye-Murray, 2003).

DHH students often face challenges with key pragmatic skills such as rapid turn-taking, managing group interruptions, maintaining topics, and repairing communication breakdowns, even when auditory input is accessible (L. E. Paatsch & Toe, 2014; Zaidman-Zait & Most, 2020). Missing out on critical information in a conversation can further limit access to more nuanced aspects of peer interaction (Punch & Hyde, 2011). To compensate, DHH students may, however, develop and apply unique pragmatic strategies either to enhance listening access or to restructure interactions as to reduce reliance on listening, both of which may be adaptive or maladaptive depending on the situation (Matthews & Kelly, 2022).

On the one hand, DHH students who frequently miss parts of a

[9] These findings should be viewed tentatively, as they were not based on research in the school context, but in the workplace.

conversation may eventually adapt by integrating information from non-auditory contextual cues to fill in the gaps, learn strategies to request clarification, or prompt others to adapt their speech (Matthews & Kelly, 2022; Szarkowski et al., 2020; Tye-Murray, 2003). While these strategies can support participation, they often require sustained cognitive effort, especially in environments that demand constant monitoring and adaptation (Bess et al., 2020; Davis et al., 2021). For example, DHH students may spend disproportionately more time managing communication breakdowns, or stay silent for longer than non-DHH peers, which can be an adaptive way to maintain participation but may also carry negative social consequences if peers interpret these behaviours unfavourably (Matthews & Kelly, 2022; Tye-Murray, 2003).

On the other hand, some DHH students may develop strategies that reduce the need for repeated breakdown repair by focusing on preventing breakdowns altogether. These may include taking longer conversational turns or initiating more topics to avoid missing topics introduced by others (Paatsch & Toe, 2016). Avoiding breakdowns can therefore come at the cost of balanced and meaningful interaction.

This highlights an important nuance: pragmatic strategies may help DHH students adapt to everyday interaction demands, yet still become maladaptive by contributing to one-sided effort, frustration, negative peer judgements, or interactions that appear smooth but lack depth or reciprocity. The effectiveness of these strategies depends not only on DHH students' capabilities, but also on the pragmatic skills of non-DHH peers and the school environment. Environments that reduce listening effort and support DHH strengths in using non-verbal cues, such as maintaining clear sightlines in group settings, or reducing noise and reverberation, may prevent pragmatic difficulties or reduce the cost of managing them.

On a social-cultural level, non-DHH peers who better understand DHH students' communicative experiences (e.g., through pedagogical intervention) may also adapt their own pragmatic behaviours in ways that reduce communicative asymmetries. This can include adjusting speaking pace and treating communication breakdown repair as a shared responsibility. Doing so may reduce reliance on (maladaptive) strategies used to avoid breakdowns. Furthermore, supporting more nuanced interpretations of DHH students' silence or other unexpected communication behaviours may help reducing negative peer judgements (Matthews & Kelly, 2022). Pragmatics fundamentally involves shared access to common conversation context. While discussions often emphasize pragmatic weaknesses of DHH students, it is equally important to recognize pragmatic limitations in hearing peers who fail to understand the underlying causes of breakdowns or to adapt their conversational behaviour accordingly. Such adaptation is widely expected in other contexts, including interactions across cultures or with second-language speakers.

Motivation to Socialize: Confidence and Stigma. The level of cooperation and acceptance from the social environment strongly influences whether DHH students' efforts to overcome participation barriers are effective and sustainable, or result in rejection and discouragement (Xie et al., 2014; Zaidman-Zait & Dotan, 2017).

In mainstream settings, DHH students often encounter non-supportive social environments, stigma and negative peer attitudes (Israelite et al., 2002). These are often reflected in daily interactions, such as when communication breakdowns are met with impatience, or when DHH students are ignored or excluded (Eichengreen et al., 2023; Rieffe et al., 2018; Xie et al., 2014; Zaidman-Zait & Dotan, 2017). During secondary school, risks of rejection and exclusion often increase as teacher supervision is reduced and peer interactions more often happen in larger, noisier group settings (Rieffe et al., 2018).

The repeated exposure to socially risky, hard-to-navigate situations can lead to stress and embarrassment (Zaidman-Zait & Dotan, 2017), feeling misunderstood or marked as "different" (Israelite et al., 2002). Adolescence may be a particularly sensitive period in this regard, as heightened self-consciousness and worries about deafness add to age-typical concerns about fitting in (Punch & Hyde, 2011). Ultimately, a lack of peer acceptance can negatively affect DHH students' self-perception, decrease self-confidence and undermine their ability to develop adaptive coping mechanisms to deal with daily challenges (Eichengreen et al., 2021).

Thus, like listening-related fatigue, the psycho-emotional consequences of negative social experiences in school can create feedback loops that weaken DHH students' capabilities to engage in future peer interactions. Reluctance to seek support or avoidance of potentially stressful situations (Zaidman-Zait & Dotan, 2017) may emerge as students try to protect themselves from further exclusion or bullying. Hesitation to disclose DHH identities or to use visible assistive technologies, particularly those perceived as socially "othering" (Kent & Smith, 2006; Punch & Hyde, 2011) can further restrict affordances for effective communication. For example, many CI users stop wearing their processors during puberty (Killan et al., 2023), which may reduce the visibility of being different but also limits the speech understanding benefits the CI provides.

This reveals a dimension of affordance "availability" that goes beyond functional access, including emotional safety and social stigma. Tools intended to support inclusion (e.g., class microphones) can inadvertently increase visibility and stigma (Zanin & Rance, 2016). More broadly, environments built on fixed or inaccurate assumptions about hearing ability contribute to structural and psycho-emotional disablism, as described in the Social Relational Model of Sonic Exclusion (Drever & Hugill, 2022; Reeve, 2015, pp. 99–113). Thus, an aspect of the environment may technically make a social affordance available, but perceived stigma or discomfort can restrict its availability in practice – especially in unsupportive social settings.

Affordance implications and possible facilitation. Beyond sensory access, affordances are shaped by emotional and energetic feasibility, which constrains how long DHH students can sustain the effort required to piece together fragmented auditory, visual, or tactile information during interaction. The willingness to invest in this effort depends on perceived payoff, emotional safety, and opportunities for recovery, as well as whether environments support rest and re-engagement. Social and cultural dimensions of the school environment are therefore critical in defining interaction affordances. Effective facilitation requires recognizing communication as a two-way process and adapting school culture and pedagogy to reduce one-sided effort by DHH students. This includes developing pragmatic communication behaviors among non-DHH peers, reducing stigma and judgement, and lowering the social and emotional costs of managing communication breakdowns and energy recovery.

3.3. Intersecting DHH capabilities and the situated school environment in a matrix of social participation affordances

Building on the framework in Fig. 1 and analyses in Tables 1–3, we designed a matrix that maps how specific DHH capabilities intersect with school environmental features to shape social affordances (see Fig. 2). It visualizes potential alignments or misalignments between action capabilities and situational-environmental conditions, offering an overview of what makes opportunities for social participation (un) available for DHH students in mainstream schools. Misalignments do not imply a lack of DHH capability (as in deficit-based models), but a situational constraint on effectively using individual capabilities, which comprise both "strengths" and "weaknesses". Hence, the framework acknowledges that reduced auditory input may be compensated by alternative modes of perception, processing, and engagement, supporting participation when the environment allows it.

To populate the matrix, we identified "intersection types" that describe how DHH students' capabilities align or misalign with external factors. These intersections reflect either the availability of an affordance or a necessary precondition for accessing it (e.g. relating to cognitive effort or motivation). The intersections are as follows:

(1) Linguistic = affordance for accessing shared language systems to convey informational content (e.g., spoken or signed)
(2) Paralinguistic = affordance for exchanging any interactional or affective cues through any language modality
(3) Situational awareness = affordance for monitoring/staying aware of surrounding events and possible interaction opportunities
(4) Sustainability of interaction = affordance (or affordance-modifier) relating to the effort of taking part in an interaction over time
(5) Recovery & Self-regulation = affordance for recovering from energy-drain, e.g. by avoiding effortful stimuli or interactions and tending to own needs
(6) Feeling safe = affordance (or affordance-modifier) relating to the emotional aspect of actions or existing in a space, which may affect feasibility of certain actions or supports

This matrix extends the framework by offering a practical tool to identify leverage points for generating more inclusive school environments, indicating how changes to certain environmental or social aspects may impact affordances for DHH students. The level of detail allows for recognition of individual differences, including sensory and cognitive capabilities, strategies, and motivational factors.

4. Discussion: A framework to bridge psychology, education, and design

In this paper, we explored *how different facets of mainstream school environments shape DHH students' social participation* through the lens of affordance theory. We viewed existing barriers not as outcomes of personal limitations but as misalignments between individual capabilities and environmental conditions, shifting the perspective from deficit-focused to relational.

Our contributions were threefold. First, we synthesized interdisciplinary research on DHH students' individual capabilities relevant to social participation through a narrative review. Second, we developed a novel affordance-based framework showing how opportunities for DHH students' social participation emerge from dynamic interactions between capabilities and situational-environmental contexts of peer interactions, such as recess (Fig. 1). Third, we created a matrix tool to support school evaluation and intervention planning by stakeholders without extensive DHH experience, while also guiding future DHH affordance research (Fig. 2).

Our results illustrated, for example, how DHH auditory capabilities can clash with typical school sound environments and peer group dynamics, leading to social deafness. We also showed how alternative sensory modalities can generate new affordances, such as lighting and seating arrangements supporting speechreading. Additionally, we considered cognitive and emotional factors influencing the availability of a social setting, such as listening effort, fatigue, and motivation, and how these settings can affect the use and success of pragmatic strategies to overcome communication barriers. In doing so, we addressed not only built-environment factors and their interaction with senses and actions, but also how stigma or peer behaviours can constrain access at a higher level.

By including a feedback loop in our framework, we emphasized how DHH students' capabilities may change dynamically over time as they adapt to their school environment. These changes may be negative – reduced motivation, confidence and energy in response to repeated barriers – or positive, involving increased use and refinement of adaptive strategies, motivation and effective energy management. Such positive developments require supportive environments that align with students' capabilities and expand their opportunities for participation.

Finally, by creating a capability-environment matrix as a concrete visualization of the affordance links emerging from the narrative review and framework, we aimed to provide a practical, actionable tool for non-expert stakeholders to identify and intervene in external school factors that can conditionally enable or constrain DHH participation. We also propose this matrix as a foundation for further DHH affordance research. The relevance of this approach for the future of inclusive schools, its limitations, and directions for future work are discussed below.

4.1. Relevance of the framework for mainstream, inclusive school

As more DHH students enter mainstream schools, driven by inclusion policies, advances in hearing technologies, and rising global rates of deafness (World Health Organization, 2025), "aural diversity" (Drever & Hugill, 2022) in student populations becomes increasingly visible. This raises urgent questions about how school environments can fairly support these learners. Although discourse on disability and hearing loss has progressed, and global networks like Cochlear Implant International Community of Action (CIICA)[10] amplify young DHH voices, implementing inclusive environments remains challenging. Many stakeholders, including educators, architects, and policymakers, lack direct experience with DHH students and may not fully understand the realities of deafness. In schools, these challenges become more difficult due to competing demands and limited resources, which constrain the development of realistic, well-informed solutions. Applying affordance theory may help bridge this gap, as similar approaches have emerged in architecture, where functional needs have often been overlooked in favour of generalized or aesthetic priorities due to weak connections with user perspectives (Koutamanis, 2006, 2024).

This paper makes a novel contribution by applying affordance theory to DHH students' social participation in school, shifting the focus from adapting individuals to modifying environments. The matrix supports this shift by helping stakeholders identify misalignments and make informed design decisions, even when they lack the time, resources, or experiential knowledge to fully understand DHH students' needs. It also extends beyond concerns like speech perception and acoustic standards, which are typically the focus of environment-level school interventions and inclusion guidelines (e.g., American National Standards Institute, 2010; Picard & Bradley, 2001), by addressing the cognitive and emotional costs of participation – factors often overlooked in technical assessments. For adolescents in particular, these costs are critical when weighing the benefits of assistive technologies against risks such as stigma or peer rejection (Zanin & Rance, 2016).

By making relationships between capabilities and environments visible, the matrix can serve as a boundary object (Star & Griesemer, 1989): a shared reference point that supports coordination across professional domains while remaining interpretable within each. It facilitates interdisciplinary dialogue grounded in lived experience and environmental design, enabling educators, architects, and policymakers to align around inclusion goals while allowing DHH perspectives to influence intervention planning.

4.2. Limitations and future research directions

One important limitation is that we did not yet test the suggested framework in this study. Future work should investigate how broadly useable the framework is, and for whom. For example, whether it is accessible, easy to understand and work with, especially for non-academic stakeholders such as educators, school staff, and designers. Furthermore, while the matrix offers a valuable starting point, it is necessarily a simplification: sensory, cognitive, and psycho-emotional capabilities are deeply interdependent, and real-world interactions often involve dynamic, overlapping chains of affordances that fluctuate across time and context (such as changing noise levels or shifting social dynamics) making any static representation inherently limited. The matrix was developed to clearly synthesize insights from the literature,

[10] https://ciicanet.org/community/our-stories/.

but future work should validate whether the chosen format and content is clear, useful, and relevant for guiding decisions about inclusive education. Future research should evaluate the matrix's practical utility through usability studies, exploring how it can be adapted for different audiences or integrated into real-world planning. Such work can refine its categories, enhance usability, and test whether the tool supports decisions and discussions that lead to meaningful change.

While the present study was co-authored by a DHH person, and the narrative review included studies that closely reflect DHH lived experiences, this work was limited in not directly co-designing the proposed framework together with DHH students. To ensure relevance and equity, future work to develop the framework and its implementation should actively involve DHH students and educational practitioners (through co-design or other participatory approaches) to mitigate bias and centre the priorities of those most affected. Participatory research in this context demands deliberate attention to values such as respect, authenticity, and empathy, which help build trust and reciprocity across communication and access differences (Fletcher-Watson et al., 2019). As the matrix is applied in practice, it may continue to evolve, with new layers or categories emerging from observed use and impact.

A further limitation is that the framework is based on theoretically grounded, but not yet empirically tested, affordance links between capabilities and situated social contexts. Thus, empirical validation of these affordances is needed. To the best of our knowledge, no studies have yet directly examined affordances for DHH students in social contexts, though affordance theory is starting to enter the field of physical accessibility or technology use for people with disabilities more broadly (e.g. Hiskes, 2024; Ochsner et al., 2022). Future research could use methods such as video analysis, or sensor data to identify micro-level affordances and barriers for DHH students in mainstream school in real-time interaction, building on Nasri et al.'s methods (2022), or develop contextually relevant affordance questionnaires (e.g. Clark & Uzzell, 2002). Such fine-grained studies would help confirm or adjust the framework's assumptions and may allow adding weights to specific links, which could help prioritizing interventions.

Finally, the current framework is limited in capturing the complexities of inclusive school design, which require attention to a highly variable group of students with different, and possibly conflicting needs. As we acknowledged in this study, DHH students are not a homogeneous group. Applying the framework through an intersectional lens (that is, attending to how multiple aspects of identity overlap) is crucial to understand how deafness interacts with dimensions such as race, gender, language background, or socioeconomic status. These intersections may shape affordances in distinct ways, revealing layered exclusions that the current framework cannot yet fully account for. Inclusive school design interventions may also involve conflicting needs across student groups, such as neurodiverse students or those with other disabilities. Future work should explore how this framework might be adapted or used in conjunction with similar tools for other populations to support negotiation and alignment of competing requirements in shared environments.

5. Conclusions

This paper offers a novel application of affordance theory to the context of DHH students' social participation in mainstream schools, reframing inclusion as a matter of capability–environment fit rather than individual adaptation. The proposed framework and matrix translate this perspective into actionable tools for identifying environmental barriers and supports across social, spatial, and institutional layers. By making the complexity of everyday school participation more visible and diagnosable, this work supports more inclusive design and planning processes. Future research should evaluate their usability across stakeholder groups and explore how they can be integrated into real-world decision-making. This approach contributes to environmental psychology by showing how affordance theory can inform inclusive environments that actively support participation and well-being for aurally diverse populations.

CRediT authorship contribution statement

Claudia A. Libbi: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Conceptualization. **Johan H.M. Frijns:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization. **H. Christiaan Stronks:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Adva Eichengreen:** Writing – review & editing, Writing – original draft, Supervision, Investigation. **Alexander Koutamanis:** Writing – original draft, Investigation, Conceptualization. **Carolien Rieffe:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

Author statement about funding sources

As the submission form asks to confirm all funding sources have been declared, but this information has been obscured in the anonymized manuscript, we provide this information here separately (to be added to the main manuscript in non-anonymized form).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the first author used Chat-GPT to improve the readability and language of some sections in the manuscript. After using this tool, this author reviewed and edited the content as needed. All authors take full responsibility for the content of the published article.

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Appendix A

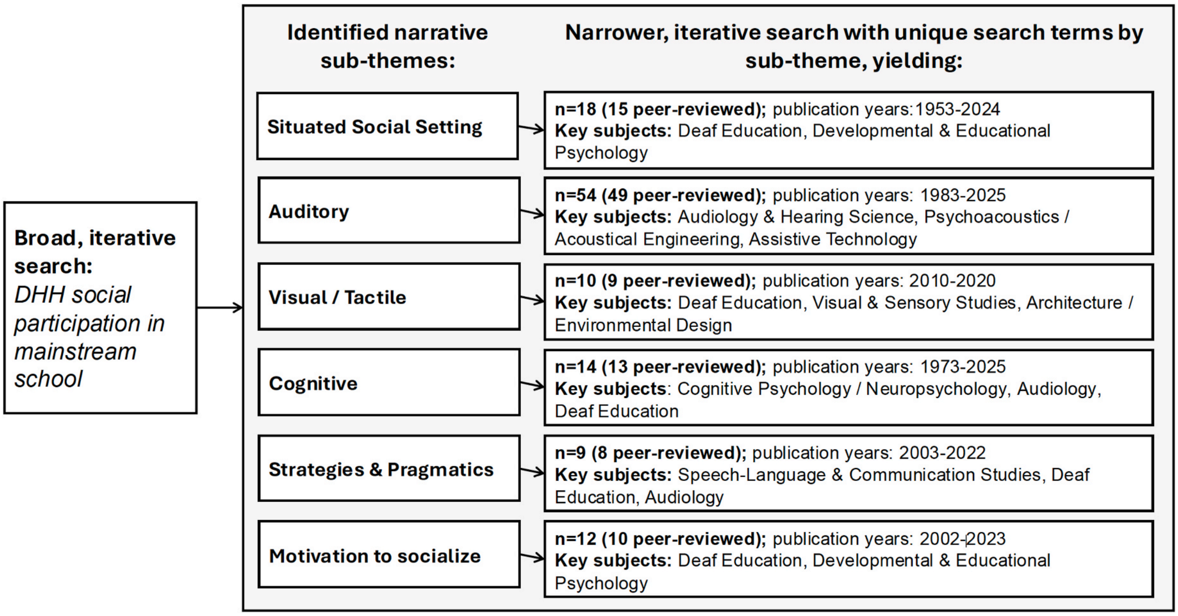

Fig. A.1. Flow diagram of the narrative review process and summary of included literature.

Table 1
Overview of DHH auditory capabilities, and when/if and why they can result in social affordances.
(*sightlines are unobstructed lines of sight between viewer and object of interest.)

DHH capability	Environment/situation factor	Relation to social affordances
(Baseline speech perception) Pitch Perception and Discrimination (hearing threshold, pitch, non-pitch cues like intensity, tempo, timbre)	- Speaker clarity (loudness, pitch use, non-pitch cues, pace) - Clear positioning and sightlines* - Use of intentional speech strategies	Enables access to speech meaning, emotional tone, speaker identity
Speech-in-noise understanding (filtering speech from background noise)	- Background noise - Reverb - Group size and density - Peer noise level	Enables participation in group conversations in noisy or busy settings
Directional/spatial hearing (esp. with unilateral deafness)	- Chaotic/new environments or other situations where surveying the auditory scene is important	Awareness of surrounding events, distractions, and interaction opportunities
(Extended auditory capabilities) wireless microphone systems	- Availability of compatible devices - Peer competence - Group size and density - DHH communication awareness - Space supports device use	Enhances speech access in low signal-to-noise ratio conditions
(Extended auditory capabilities) Lowering/muting environmental sound on device (device-specific)	- Social setting that allows disengagement - Peers are informed - Institutional flexibility	Enables recovery without negative social effects

Table 2
Overview of DHH visual-tactile capabilities, and if, when, and why they can result in social affordances.

DHH capability	Environment/situational requirements	Relation to social affordances
Sign-supported language	- Clear visual access to speaker - Unconstrained gesture space - Sufficient lighting - Peer sign knowledge - Supportive positioning and sightlines	Supports speech understanding
Speechreading	- Clear visual access to speaker - Good lighting - Peer positioning enabling clear speech and sightlines	Supports speech understanding

(*continued on next page*)

Table 2 (*continued*)

DHH capability	Environment/situational requirements	Relation to social affordances
Reading visual & tactile communication cues (facial expressions, body language, tactile gestures)	- Clear visual access - Good lighting - Peer positioning and movement	Paralinguistic cues, turn-taking, and other social cues
Use of peripheral visual & vibro-tactile information of surroundings (spatial awareness)	- Visually open layout - Space allows informal behaviour - Peer positioning and movement	Supports spatial awareness, e.g. spotting interaction opportunities, anticipating interruptions, gathering context cues

Table 3
Overview of factors related to (auditory-)cognitive mechanisms, related pragmatic skills and motivational aspects, and when/if and why they can mitigate access to social affordances.

DHH capability	Environmental/situational conditions affecting this capability	Relation to social affordances
Listening effort & fatigue risk	- Noisy or reverberant spaces & degraded auditory input	Modulates interaction ability; affects endurance; can lead to disengagement when effort outweighs benefit
Cognitive strain & split attention	- Unpredictable social dynamics - Sustained or cognitively demanding conversations - Limited opportunities for listening breaks - Fast-paced or overlapping group talk	Affects interaction fluency/experiencing communication breakdowns or distractions
Use of repair strategies (Pragmatic & strategic competence, use of self-advocacy, recovery & self-regulation strategies)	- Fast-paced or overlapping group talk - Implicit or unclear social rules - Unpredictable or socially unsafe settings - Negative peer reactions to repair attempts - Environments that allow vs. discourage listening breaks - Institutional flexibility or rigidity - Social norms that normalize or stigmatize pausing/ withdrawing	enables recovery from communication breakdowns, enables sustainable participation (manage energy, protect from fatigue) and protects wellbeing
Social confidence (psycho-emotional resilience, identity …) & motivation (cost–benefit appraisal)	- Supportive vs. non-supportive peers - Past experiences of exclusion or rejection - Likelihood of successful interaction (also based on difficulty, e.g. in case of noisy or hard-to-navigate group settings) - Value placed on social goal - Stigma and negative peer attitudes - Visibility of devices - Experiences of being "othered" or misunderstood - Structural disablism in school environments	Shapes willingness to participate, persistence, and social risk-taking, affects self-expression and opportunities to ask for support/self-advocate

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