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REVIEW

Towards equitable artificial intelligence for deaf and hard of hearing (DHH) and disabled communities: ethical challenges and co-development

David G. Loughrey[1,2] · **Caro Brosens**[3] · **Rachel A. Moiselle**[2] · **Dimitar Shterionov**[4] · **Vincent Vandeghinste**[5,6] · **Andy Way**[1,7] · **Lorraine Leeson**[2,7]

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Abstract
Artificial Intelligence (AI) technologies offer the potential to reduce barriers to communication and facilitate greater participation of Deaf and Hard of Hearing (DHH) and disabled communities in society. However, there is a risk that such technologies could have a disproportionately negative impact on these communities and exacerbate existing social inequities. In this narrative review, we examine key ethical issues surrounding AI use in the context of DHH and disabled communities. These include issues related to bias, accessibility, equity and privacy, and others. We propose a grounded, co-constructed participatory approach that focuses on the ethical co-development of these technologies through the active involvement of DHH and disabled individuals in interdisciplinary research. This inclusive approach is imperative to tailor AI solutions to the unique perspectives and experiences of DHH and disabled individuals and ensure they reduce, rather than perpetuate, societal barriers experienced by these minority groups.

Keywords Deaf and hard of hearing (DHH) · Hearing loss · Disabled people · Artificial intelligence · Ethics · Machine learning

✉ David G. Loughrey
david.loughrey@dcu.ie

Caro Brosens
caro.brosens@vgtc.be

Rachel A. Moiselle
MOISELLR@tcd.ie

Dimitar Shterionov
d.shterionov@tilburguniversity.edu

Vincent Vandeghinste
vincent@ccl.kuleuven.be

Andy Way
andy.way@adaptcentre.ie

Lorraine Leeson
leesonl@tcd.ie

1 Dublin City University, Dublin, Ireland
2 Trinity College Dublin, Dublin, Ireland
3 Vlaams Gebarentaal Centrum, Ghent, Belgium
4 Tilburg University, Tilburg, Netherlands
5 University of Leuven, Leuven, Belgium
6 Instituut voor de Nederlandse Taal, Leiden, Netherlands
7 ADAPT Centre, Dublin, Ireland

1 Background

AI technologies are rapidly reshaping a wide range of sectors, including healthcare [1–3], education [4, 5], agriculture [6], and communications [7]. During the COVID-19 pandemic, AI platforms played a pivotal role in accelerating vaccine and drug discovery [8], highlighting the speed and scalability that these tools can offer. More recently, the widespread release of generative AI tools, such as OpenAI's ChatGPT,[1] has intensified debate around the societal impact of AI, particularly in sensitive domains like education, research, and medicine [9, 10]. While these technologies offer the potential to improve quality of life and reduce barriers for marginalised groups [11], their deployment is not without risk. Without careful design and inclusive development, AI systems can inadvertently reinforce existing social inequalities [12–14] and can even have a negative impact on languages themselves [15]. It is therefore essential to consider ethical implications proactively, especially regarding

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how AI may affect communities that have historically been excluded from technological development and policy decision-making. In this review, we assess the current literature on AI and ethical considerations in the context of the DHH communities. We focused on several key issues including accessibility and autonomy, equity and identity, and issues of bias, privacy, and security which have been highlighted in prior work [11, 16–19] and propose a holistic approach for the ethical co-development of these technologies.

2 DHH communities: cultural and medical perspectives

In this paper, we use the term DHH to refer to a broad and heterogeneous population that includes people with varying degrees and experiences of hearing loss. This group encompasses both culturally Deaf individuals who use signed languages, and those who are deaf or hard of hearing due to acquired hearing loss who may or may not identify with the Deaf community [20]. Following Allen [in 21, p. 54], we use "deaf" to refer to all deaf people, regardless of their communication modality, whether they come from a deaf family, if they learned to sign, whether they choose to speak as well as sign, or whether they have a cochlear implant, while we use the term 'Deaf' (upper case D) to refer to the community and culture. Members of Deaf communities may include both deaf and hearing individuals who are fluent in a signed language and actively participate in the community's cultural life [22, 23]. Additionally, there are individuals who are born deaf but do not use a signed language and those who have an acquired hearing loss, something which may happen at any point across the lifespan, but which occurs more commonly as people age [24]. Within these communities, many individuals identify as members of a sociolinguistic minority [25, 26], rather than identifying as having a disability or aligning with the broader disability community [27]. A signed language may be the preferred language of Deaf community members, and the use of signed language can include others who are not deaf but have fluency in signed language. Current estimates indicate that there are more than 300 distinct signed languages in use by approximately 70 million people globally as their first language [28]. During the past decade, there has been an upsurge in recognition of signed languages in many countries around the world [29–33] and their inclusion within significant international instruments like the United Nations Convention on the Rights of Persons with Disabilities (CRPD) [34].

From a medical or audiological perspective, deafness includes a wide spectrum of hearing loss—ranging from mild to profound—which can occur at any point across one's lifespan. It is estimated that over 5% of the world's population, or around 443 million people, have a significant hearing loss [24]. This number is projected to increase to over 700 million by 2050. Acquired hearing loss can impact quality of life and is associated with an increased risk of several adverse health outcomes including dementia [35, 36]. Strategies to manage a hearing loss can range from preventive measures to rehabilitative technologies such as hearing aids or cochlear implants. Additionally, internationally, DHH people's rights are protected under disability grounds, including through the CRPD, which prohibits discrimination on the basis of disability [34]. Despite these advancements, along with the progress in rights for disabled people, DHH people still face formidable challenges in obtaining equitable access to education and employment opportunities [24, 37–39]. However, the potential of AI-based technologies warrants genuine enthusiasm as these technologies may offer innovative and inclusive solutions to a wide range of issues for DHH people. As a result, in this paper, we draw more broadly literature on how AI impacts disabled people while profiling concerns specific to DHH people.

3 AI and DHH communities: opportunities and ongoing challenges

Technologies that translate between spoken, written, and signed languages hold significant promise for bridging communication and cultural divides between Deaf, hard of hearing and hearing community members [40–48]. If these tools are ethically developed and made equitably available, they could reduce cultural and linguistic barriers and foster greater inclusion. However, progress has been hindered by several challenges.

Given that signed languages are complex, natural languages with rich grammatical structures, visual-spatial components, and cultural depth, any technology seeking to facilitate translation must preserve these aspects and accurately recognise the sophisticated ways in which signers communicate meaning [43, 49, 50]. In this respect, focusing solely on one aspect, such as hand movements or fingerspelling [51], could lead to substandard technology that cannot perform on par with a signed language interpreter [44]. AI systems may not accurately recognise or misidentify facial expressions during signed language communication [52]. Technologies that identify and translate certain aspects of a signed language, such as finger-spelling or hand movements, only capture a narrow range of signed language expressions and miss the sophisticated ways in which signers communicate meaning, which have been difficult to capture in AI models [51].

These challenges can be grouped in the following categories (which we discuss in detail below): (3.1) processing capacity of current technologies; (3.2) high dependency on data and (3.3) user involvement and user impact.

3.1 Processing capacity of current technologies

Despite the growing performance capacities of current AI-enabling hardware and software, e.g. the advanced graphics processing units (GPUs) capable of processing massive neural networks—the heart of any current large language model (LLM)—as well as state of the art neural architectures, such as the transformer [53], there is still a gap when it comes to processing and translating signed languages. This gap does not stem solely from data limitations. Current translation systems and LLMs are primarily developed for spoken languages represented in written form. Signed languages, however, exhibit simultaneity, requiring multi-cue processing across parallel channels. This introduces additional representational dimensions that prevailing neural architectures are not explicitly designed to handle. Consequently, typical SLMT pipelines rely on multi-stage processing steps that reduce this multimodal complexity [54], yet these approaches remain less effective than spoken-language machine translation.

3.2 High dependency on data

In addition to these architectural challenges, SLMT systems require substantial volumes of annotated multimodal data, which brings us to our second challenge category: high dependency on data. To address this challenge, researchers tend to rely on various type of additional technologies—from wearables to body and pose estimators. Wearable technologies, such as gloves, can capture precise hand movements. Gloves, however, fail to capture the nuanced intricacies of signed languages including critical aspects such as body movements and facial expressions [51, 55–58]. More advanced technology, such as 3D motion capturing, can be considered an improvement (from gloves) from a technological perspective, as it allows fine-grained finger, hand and body movements to be captured, and in certain setups even facial expressions. However, not only it is a costly process, but it is also a restrictive technology, as users need to wear specialised, expensive equipment and software, and it requires time for calibration and use in specially designed labs. At the same time, from a medical perspective, AI tools have the potential to enhance rehabilitative techniques in hearing and speech therapy [59, 60]. AI tools could aid clinicians in understanding individual differences in auditory impairment and clinical outcomes in patients following cochlear implantation and thus support personalised treatment pathways [61–64]. Additionally, such tools could facilitate further discoveries in attempts to uncover the neural mechanisms for how conditions such as tinnitus arise subsequent to hearing loss [65].

In prostheses, such as hearing aids and cochlear implants, AI may provide advanced solutions to improve speech perception under challenging listening conditions characteristic of real-world environments [66–73]. Automatic captioning using machine learning can improve access in a range of environments such as audio-visual content, online and in-person meetings and in face-to-face conversation or telephone conversations [74, 75]. Smart glasses may facilitate speech-to-text translation allowing DHH people to see captions of conversations in real time [76]. Another creative application is lip-reading technology to facilitate speech perception [77–79]. The application of AI in healthcare therefore has the potential to facilitate more inclusive and effective healthcare and provide communication solutions for DHH individuals.

As noted above, despite the advances in AI-enabling technology, data is a main challenge when it comes to the development of signed language technologies. Vandeghinste, De Sisto [80] point out the difficulties that stem out of the lack of high-volume, high-quality signed data, suitable for AI. Initiatives such as the NGT-HoReCo [81] and GoSt-Parc-Sign [82] acknowledge the demand for domain-specific data to drive AI in order to leverage its potential, as noted above. It is also necessary to point out that researchers often tend to ignore the link between data and community, as underscored by Caselli, Cibin [83].

3.3 User involvement, needs and impact

The third challenge category, user involvement and the potential impact on the users, is perhaps the most complex one. The growing integration of AI technologies into our societies and economies raises ethical issues about how they may impact minority groups, including DHH communities and disabled people [13, 14, 84]. It is important to consider these ethical issues, as failure to do so may lead to potential adverse impacts or delays in usage or inappropriate deployment of AI-based solutions to challenges faced by DHH and disabled communities [85]. In recent years, there has been a proliferation of published ethical guidelines and frameworks for the development of AI technology, particularly since 2018 [86–98].Despite this, there is still very little literature that addresses the intersection between ethical issues in AI technologies and the unique challenges faced by DHH and disabled communities [99, 100]. A recent scoping review that critically examined the degree to which ethical issues and disability were considered in the AI literature found that concerns related to disabled individuals and the DHH communities received minimal attention [101]. This is a significant gap in a critical area for research.

These gaps are not merely theoretical but become particularly evident in how AI tools are experienced and adopted in practice. DHH and disabled populations are highly heterogeneous, with diverse needs and communication preferences impacting on accessibility. For example, native sign language users in a medical consultation may require accurate, culturally nuanced signed language translation, whereas a hard-of-hearing person in a noisy workplace meeting or lecture may depend primarily on highly accurate real-time speech-to-text captioning. Individuals with non-visible disabilities may have concerns regarding privacy when using AI tools to support daily activities. These differences highlight why a one-size-fits-all approach to developing AI tools can fail.

While AI technologies hold considerable potential to address the diverse requirements of DHH people, current systems remain limited in their ability to effectively process signed languages [102]. This raises important questions regarding their suitability for deployment in real-world contexts. For example, in healthcare, AI based tools could provide scalable solutions to address issues that may arise with the projected increase in demand for health services, particularly in lower-income global regions [103, 104]. However, in Europe, while AI tools remain subpar, Deaf communities rightly raise concerns about overly early adoption, cost, and prefer human interpreters [47, 105].

While there are general ethical issues (such as privacy) that affect the overall population, there can also be distinct concerns that are specific to minorities including DHH and disabled communities. Contrary to an assumption that AI systems may be more objective than human judgement, such tools may inadvertently replicate and amplify human biases [e.g., 106], leading to a disproportionate adverse impact on minorities [11, 101, 107–109]. For example, an AI model used to assess how likely people are to commit a future criminal offence incorrectly identified African-Americans as having a higher risk compared to White Americans [110–112].

Minority groups, particularly individuals with disabilities and DHH communities, are often underrepresented across various socioeconomic domains [113, 114]. This may consequently lead to their underrepresentation in projects which build AI technology for public use, potentially leading to ethical oversights and subsequent adverse outcomes for these groups upon deployment [55, 56]. An additional challenge is that disability is different to other protected characteristics due to the vast heterogeneity in how disabilities manifest and their impact on function [115]. It is therefore hugely beneficial to consider separately the possibly unique impact and ethical development of AI tools with minorities such as the DHH community [11, 101, 107]. Without inclusive design, these tools may inadvertently worsen inequities or delay appropriate interventions [85].

4 The ethics gap in AI development for DHH and disabled communities

The challenges outlined above give rise to a set of interrelated ethical concerns for DHH and disabled communities [11, 16–19]. In this section, we consider the implications of current design and deployment approaches in four interconnected domains.

4.1 Accessibility and autonomy

To ensure that AI applications are available equitably for DHH and disabled individuals, it is vital to consider how they may impact accessibility across the life of their development from conceptualisation to when they are used in the community. It is equally important to ensure that DHH individuals have equitable autonomy in using these applications within society [89]. Accessibility refers not only to physical or technical usability, but also to cultural and linguistic relevance. Autonomy, meanwhile, refers to the ability of DHH users to engage with these technologies on their own terms and without undue constraints. However, the challenges involved in acquiring datasets reflective of DHH experiences may mean that these technologies are not optimally oriented for the experiences of DHH people [44].

The emergence of AI technologies without accessible solutions, such as voice-based services without captioning, can inadvertently intensify inequalities, rendering certain technologies less accessible or inaccessible for DHH communities [11, 116]. The increasing ubiquity of speech interfaces in workplaces and daily life can pose accessibility hurdles for the progression of DHH individuals in society [116, 117] and emphasise the phonocentric nature of society. Moreover, these applications should include options that mirror cultural or linguistic differences and seek to bridge the digital gap between majority spoken/written languages and signed languages. Some signed language translation technologies have, to date, incorporated avatars which members of Deaf communities have found to be unrealistic [44, 56, 118, 119]. Such technologies, while intended to enhance autonomy, may inadvertently curtail it. For instance, technologies that might be seen as cost-effective, scalable replacements for what are considered to be expensive accommodations like signed language interpreters would inadvertently reduce accessibility if they fail to meet the standards of current services [13], and this is a real and pressing concern for Deaf communities [47, 48, 56, 105, 120]. Thus, it is imperative to involve representatives from DHH communities in any public authority decisions regarding this matter [121]. These concerns are reflected in stakeholder perspectives. For example, a deaf contributor in a British Deaf Association discussion paper notes:

> "Human interpreters understand cultural nuances and context within BSL and deaf culture, which AI may not fully grasp. They can adjust their signing to reflect the appropriate tone, register and emotional context of a conversation. Furthermore, human interpreters build trust and rapport with the deaf client, offering emotional support and reassurance in sensitive situations. They can adapt their signing to adjust to emergent issues (e.g. clarifications, to suit the individual preferences of the deaf client, e.g. speed or specific regional dialects). AI solutions may be generic or overly formal which may not work with the user's need… Human interpreters, in my opinion, remain essential for their ability to provide culturally competent, empathetic and accurate communication in diverse and complex situations" [105].

Furthermore, these technologies should be developed with clear guidelines on their capabilities and limitations to avoid false impressions [11, 122]. For example, an interviewer for a job should not be led to believe that automatic speech recognition can completely mitigate a hearing loss, as it could result in a false attribution of communication difficulties to a candidate's capabilities rather than to the system's inaccuracies [123]. Research has found that when in conversation with a DHH person, individuals who were aware that speech recognition technology was being used to assist speech perception changed from a manner of speech intended to aid comprehension to one which was more natural and harder for the technology to accurately transcribe [13, 124].

As AI algorithms continue to advance in sophistication, they present a range of choices within applications, such as different styles in signing avatars [48, 120] or, for those with cochlear implants or hearing aids, the option to adjust the processing of sound and speech. However, in some cases these can be sub-optimal or may not take into consideration individual user experiences. An AI approach that optimised hearing-aid gain parameters based on user preferences revealed substantial inter-individual variation in preferred gain settings among DHH participants, highlighting the difficulty of predicting optimal adjustments [125]. In educational spheres, AI solutions like personalised learning systems should be designed to cater to a range of learning needs, including those of DHH students [126], though again, we emphasise the need for co-creation with DHH and disabled community members [47, 58, 97]. Thus, system performance must be evaluated across diverse real-world settings to ensure accessibility and support user autonomy in practice [127].

4.2 Equity and identity

The use of AI-driven technologies, despite their potential benefits, can pose significant challenges regarding equity, especially for DHH individuals [128]. For example, the potential of AI can be harnessed in different ways—through commonly used devices, such as mobile phones, to specialised, dedicated devices, such as cochlear implants. These not only cover a wide range of use-cases and settings, but also have a varying financial burden. Smart hearing aids, which could be potentially of huge benefit for some DHH users [129], may be expensive for DHH individuals with lower incomes, thereby deepening existing inequities rather than alleviating them.

Communities of signers often face societal neglect and health disparities and thus require specific consideration [30, 130, 131]. Such disparities became more evident during the recent COVID-19 pandemic, when DHH signers experienced more significant difficulties accessing health information than the general population [132–134]. Additionally, the guidelines on the ethical development of AI technologies and the data used may not reflect the diversity of the global population for which they are intended [94, 95]. This may mean that the output does include allowances for differences due to cultural identity, which is a particular concern for DHH signed language users [58].

In this context, cultural identity must be treated as central to ethical AI development, not as an afterthought. At present, research on signed languages is still in its initial phase, with existing systems demonstrating inadequate performance in processing complex signed sentences [45]. This is also reflected in the results of the Conference on Machine Translation (WMT) shared tasks on Sign Language Translation [135, 136] which show subpar translation performance (as compared to human interpreters, but also as compared to the current state of the art in spoken MT). The deployment of these technologies has the power to shape behaviour and norms over time [13, 124]. More broadly, it has been posited that AI will facilitate a cultural shift [14] raising concerns that dominant technological models may inadvertently drive cultural homogenisation or prioritise efficiency over inclusion. For communities of signers, it is crucial that this shift is managed so that any disparities are not further ingrained in a society that increasingly uses AI technologies [14]. Such barriers should not prohibit the development of these technologies, but they do highlight the need to develop them responsibly.

4.3 Bias

AI-driven technologies can either contribute to greater social inclusion for DHH people and their families or exacerbate existing inequalities. In contrast to traditional rule-based systems, modern AI models are mainly data-driven, i.e. developed through training on huge datasets to perform specific tasks such as speech recognition, diagnosis, or candidate selection [109]. However, AI systems are unable to distinguish between data patterns that reflect real-world differences and those that reflect social bias [108, 109]. As a result, any bias present in the training data, or in the absence of certain data in the training sets, or in the selection of goals can be encoded into the system itself with potentially adverse consequences for minority groups [137].

A major source of algorithmic bias has been the underrepresentation of minorities in these datasets which has the risk of amplifying or exacerbating current real-world biases in society [11, 13, 16–19]. In the case of sexism or racism, an algorithm trained primarily on males with lighter skin produced a higher rate of classification errors for darker-skinned women [138]. Similarly, speech recognition tools are less accurate for women and ethnic minorities because there has been underrepresentation of samples from these groups during development [13, 139, 140]. In addition, such systems are almost never trained on signed languages, further compounding issues of underrepresentation for DHH users [56]. In healthcare, minority groups have been misdiagnosed by AI tools trained primarily on majority-population clinical data, particularly for psychiatric conditions such as schizophrenia [108, 141–143]. Similarly, AI technologies used in diagnosis may have adverse consequences for DHH communities if their development fails to account for diverse linguistic norms and communication modes.

Disability can be substantially heterogeneous and in large datasets, disabled people, or minorities, such as deaf signers, may be regarded as outliers [85, 115]. This may lead to AI-based software inadvertently building in bias against DHH people. For example, AI-driven hiring tools may rely on verbal expressions and tone of voice to determine the quality of a candidate, leading to misjudgements and potential discrimination against DHH job applicants [13]. This is a concern as disabled people have a higher rate of unemployment, being more than twice as likely to be unemployed as their non-disabled peers [144]. Also, in the tech industry, these systems have been observed to be biased against female applicants [145]. Although their effects on DHH individuals are less well studied, they may also have significant adverse impacts [123]. Moreover, these risks can multiply when considering intersectionality. For example, there may be compounded disadvantages from overlapping biases related to race, gender, and disability [146]. Without deliberate design interventions and diverse data inclusion, AI systems may continue to reflect and reproduce the exclusions already present in broader society.

4.4 Privacy and security

Privacy is a critical issue for disabled people, and for DHH individuals. Disclosure of disability status can risk discrimination and reduced employment opportunities, even when the disability has a negligible impact on productivity [115]. The development of AI systems often requires the use of personal data, including disability status, to function effectively. Potential tensions may arise in the attempt to balance the use of representative datasets to build these systems and the ethical obligation to protect individual privacy [147].

For DHH individuals, the situation is especially complex as they may be more reliant on tools such as speech-to-text software, hearing aids, or smart glasses to overcome communication barriers in daily life. Certain types of tools may collect data such as speech patterns, which can inadvertently expose disability status and/or data on health conditions such as an increased risk of neurodegenerative conditions [11, 148–150]. Additionally, data such as computer mouse movements which can help identify these conditions might not even be recognized as personal health data by regulatory authorities [151]. As some DHH individuals may be more reliant on such technologies, they may be at greater risk of data security vulnerabilities in respect to health or disability status.

As assistive technologies evolve, their surveillance capacities may also increase. Applications using AI in devices such as hearing aids could extend beyond the original purpose, encompassing physical activity monitoring, social activity tracking, and fall detection [152]. With the advancement of brain-computer interface technologies and their potential use in hearing assistive technologies, these concerns could amplify [84]. Through the use of AI, more options to collect such data are becoming available such as telemedicine, including through neural prostheses, which may gather and transmit confidential health and disability-related data [61–64, 153]. There is also growing concern over the rise of digital phenotyping, where AI models infer disability or deafness based on speech patterns, typing behaviour, or online activity [108]. While such models may support earlier diagnosis or personalisation, they risk identifying users without their knowledge or consent thus raising new challenges for data protection and informed disclosure.

To mitigate these risks, it is essential to ensure that DHH users retain full control over the collection, storage and sharing of their personal data. It should be explicit how data collection may impact users of any technology regarding their disability status or primary mode of communication:

verbal-auditorial or visual-gestural. Sufficient security for such data should be considered given the high granularity of data that can be collected which might result in identifiable information [151]. This also extends to the use of facial features which are crucial for developing signed language AI tools.

Finally, it is important to consider how technologies designed to support DHH individuals may affect the privacy of others. For instance, smart glasses with live captioning or voice recognition could be perceived as intrusive by those being recorded. However, studies suggest that the public may be more accepting of such technologies when they are clearly intended to support accessibility for disabled people [11, 154].

5 Ethical guidelines and inclusive AI design for DHH communities

In recent years, the development of ethical guidelines for AI technologies has received considerable attention, with numerous publications in this growing field [86–95, 155, 156]. As the global discourse on ethical AI progresses, a consensus is forming around core principles such as fairness, transparency, privacy, and accountability [88]. However, it is crucial that such ethical guidelines integrate the perspectives and experiences of disabled individuals, and from our perspective, DHH individuals, for a truly inclusive technology landscape. Such a framework should not merely conform to existing regulations but should actively guide the development of AI [84].

5.1 From ethical principles to practical implementation

The World Health Organization (WHO) estimates that around 1.3 billion individuals have a significant disability [157]. Over recent decades, the conceptualisation of disability has shifted from the medical model which positions disability as an individual deficit to the social model which recognises that social, environmental, and systemic barriers are often a source of exclusion [158]. This change affords a view whereby adjusting external conditions can mitigate the disabling impact of an impairment and support individual autonomy. More recently, a human rights-based model has emerged which favours a proactive approach to achieving an equitable position in society which enhances the autonomy of disabled people. Importantly, DHH organisations and many individuals are part of this broader disability community. The distinct cultural and linguistic context for DHH communities, along with how these intersect with evolving models of disability, must be fully integrated into ethical frameworks guiding AI development.

Given the rapid pace of technological advancement and the early stage of many AI tools, it can be challenging to fully anticipating their long-term social impact and potential consequences [159]. Regardless, it is important that the development of ethical frameworks is proactive and evolves in parallel with innovation rather than adopting ad hoc initiatives [14], particularly as the fast-paced nature of the field may leave marginalised users unprotected by existing regulations [91, 151]. This presents an opportunity to ensure that such tools are equitable and ethically developed prior to their deployment.

The continuous development of ethical frameworks for AI technologies requires a holistic approach that involves partnerships across sectors, including academia, industry, and user communities [160]. Education in ethical principles is critical [84, 161], but translating what can be abstract values into practical application can be a challenge, particularly in the context of engineering development where ethics is often viewed as peripheral [86, 147]. Current research suggests that advising software developers to follow a code of ethics has limited influence on their decisions, likely because abstract principles are difficult to apply within the trial-and-error nature of software development [90, 91, 162, 163].

For DHH individuals, these challenges are particularly pronounced. Tools such as signed language translation software represent important advances, but their real-world readiness is often overstated [51, 56, 118]. Too often, the burden falls on users to adapt to poorly designed technologies that fail to reflect their needs, thereby reinforcing barriers to social participation [11]. A more ethical and effective approach involves iterative, user-informed co-design where DHH individuals are included from the outset, and their experiences shape development [122, 164]. In the context of AI tools intended for widespread use, this can be done by including DHH people in datasets with precise labelling of status and communication preferences [165], rather than relying on simulated datasets [11]. To this end, it is paramount that developers have clear accountability for AI-based technologies [103]. Emerging initiatives led by Deaf institutions further emphasise that inclusion must go beyond consultation to meaningful leadership and governance [166]. This approach, which capitalises on the lived experiences of DHH people, offers a solution to bridging the gap between abstract ethical principles and the practical realities of engineering AI systems for real-world use [56, 167, 168].

With respect to signed language translation tools, the sustained involvement of the DHH communities in the development process is crucial. The perspectives, linguistic practices, and cultural values of prospective users should be incorporated into the development of AI systems from the planning stage [14]. Ideally, DHH experts would be part of each and every team working on machine translation for signed languages. Further, the development process should include a representative group of target users, or where this is not feasible, appropriate evaluation metrics [13]. This is to ensure that signed languages are appropriately captured and preserved through customised AI models for DHH people. Signed languages, with their visual-spatial grammars and rich cultural nuance, must be accurately represented in AI models to avoid reductive or ineffective outcomes. Where such systems are intended for real-world use, they should undergo focused pilot testing and prospective validation with DHH people to ensure functionality and acceptability in diverse environments [109, 169]. In addition, the practical implementation of these approaches requires consideration of the resources needed for development, pilot testing, and scaled deployment. The impact of such technologies on cultural and social systems should be continuously assessed [14]. SignON[2] is an example of a project intended to support DHH communities, but which also embedded collaboration between members of the academic and DHH communities as well as involving people from different disciplines such as computer science, psychology and linguistics including expertise in signed languages [40, 48]. Furthermore, DHH groups were key partners in this project, offering essential guidance to the direction the project took at it unfolded. Even then, there is room for improvement. De Meulder et al. [170, p. 2] argue for:

> "… co-creation as a transformative activity that fundamentally alters the status quo and levels the playing field. This necessitates increasing the number of deaf researchers and enhancing AI literacy among deaf communities. Without these critical transformative actions, co-creation risks merely paying lip service to deaf communities."

The optimum approach, then, to the ethical development of AI-based tools requires a commitment to transformative approaches to 'doing' AI *with* DHH communities rather than *for* them. It requires a balance between individuals with technical experience, and those with expertise in the ethical issues arising in AI. Fundamentally, it requires those with cultural or lived experience to be key members of project teams across the disciplinary domains engaged in the work at hand. The work of Lepp and colleagues [97, 171, 172] builds a framework of co-creation for signed languages translation and Natural Language Processing projects. It acknowledges that, moving forward, such projects should be developed involving the experts with the right capacity, knowing and representing the Deaf communities. To accomplish such endeavours in the future, we need the education and training of experts that know and/or are representative for the user community. This requires a commitment to developing the pipeline of DHH experts in these fields. Cross-disciplinary collaboration between computer scientists and social scientists and ongoing, meaningful exchanges with members of DHH communities is crucial [13, 169]. In addition, it may be helpful to include ethicists in development teams [173] with representative stakeholders to develop an ethical reasoning for the context in which the technologies may be used [109]. AI systems are complex and the real-world context in which they may be intended for use will involve many variables leading to unpredictable and unintended outcomes. Inclusion of representative members of the community in their development and deployment will help ensure negative impacts are minimised and AI tools are equitable and better prepared to cater to diverse user needs [116, 174].

5.2 Key action items for ethical and inclusive AI development with DHH and disabled communities

Based on the preceding discussion, the following key action items outline practical considerations for the ethical and inclusive development of AI tools for DHH and disabled communities [11, 16–19, 86–95, 97, 155, 156, 171, 172]:

- *Embed lived experience through co-creation*: involve DHH and disabled individuals as core members of development teams across all stages, ensuring representation that reflects variation in cultural identities, communication preferences, and intersectional experiences.
- *Develop representative datasets and models*: use real-world data from DHH and disabled users with appropriate labelling, and design models that capture the diversity of user experiences, avoiding reliance on simulated or overly homogeneous datasets.
- *Design, pilot, and test across real-world contexts*: develop and test AI tools across different settings, to ensure robust performance for different user groups, while accounting for the resources required for development, testing, and scaled deployment.
- *Establish clear accountability mechanisms*: developers and organisations should take responsibility for the ethical design, accessibility, fairness, performance, and social impacts of AI tools on DHH and disabled users.
- *Foster interdisciplinary and cross-sector partnerships*: promote collaboration between computer scientists, clinicians, social scientists, ethicists, and DHH/disabled community organisations to bridge technical development with real-world needs.

[2] https://signon-project.eu/

- *Invest in education and pipeline development*: expand training and mentorship pathways to increase the number of DHH and disabled professionals in AI and related fields, while integrating practical ethical training for all development teams
- *Conduct continuous, context-sensitive impact assessment*: regularly evaluate real-world performance, social, and cultural effects with diverse subgroups of DHH and disabled users and implement mechanisms to adapt or mitigate harms as AI technologies evolve.
- *Prioritise proactive and evolving ethical frameworks*: create and maintain ethical guidelines tailored to the needs of DHH and disabled communities that evolve alongside AI technological developments.

6 Conclusion

AI technologies hold significant potential for DHH communities. It is imperative that the development of these technologies is guided by ethical frameworks that help to ensure they take the needs and concerns of DHH communities into account. There is a pressing need for further interdisciplinary research at the intersection of AI, Sign Linguistics, Deaf Studies and Disability Studies, and to explore the ethical implications of these technologies [101]. In particular, this requires attention to key ethical domains identified in this paper, including accessibility and autonomy, equity and identity, and issues of bias, privacy, and security. Such research is critical for developing comprehensive, inclusive guidelines that balance the risks and benefits of AI for both the general population and groups that may be at risk of vulnerability [108] and these also open up conversations around themes that have wider application (image generation and usage, bias in such images, emotion in AI, etc.). As discussed, DHH people continue to experience systemic challenges in areas such as education, healthcare, and employment. AI must be designed not only to mitigate these barriers, but also to avoid amplifying existing societal biases. Nor must AI risk trampling upon the hard won linguistic and cultural rights of DHH communities. Only through inclusive, participatory, and ethically grounded development can AI truly serve the diverse needs of all users.

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Declarations

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