Accessibility in Action: Co-Located Collaboration among Deaf and Hearing Professionals

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Although accessibility in academic and professional workplaces is a well-known issue, understanding how teams with different abilities communicate and coordinate in technology-rich workspaces is less well understood. When hearing people collaborate around computers, they rely on the ability to simultaneously see and hear as they start a shared document, talk to each other while editing, and gesture towards the screen. This interaction norm breaks down for teams of people with different sensory abilities, such as Deaf and hearing collaborators, who rely on visual communication. Through interviews and observations, we analyze how Deaf-hearing teams collaborate on a variety of naturalistic tasks. Our findings reveal that Deaf-hearing teams *create accessibility* through their moment-to-moment co-located interaction and emerging team practices over time. We conclude with a discussion of how studying co-located Deaf-hearing interaction extends our understanding of accessibility in mixed-ability teams and provides new insights for groupware systems.

CCS Concepts: • **Human-centered computing** → Empirical studies in accessibility; • **Human-centered computing** → Computer-supported cooperative work

KEYWORDS

accessibility; Deafness; group work; video analysis

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1 INTRODUCTION

CSCW has a long history of studying co-located small group interaction in diverse workplace settings, such as airport control rooms [36,69], the London Underground [42–44], and in medical contexts [71–74]. An emerging but relatively unexplored area of CSCW involves analyzing how teams of people with diverse physical, cognitive, or sensory abilities collaborate. While assistive technologies promise to make workplaces and learning environments more inclusive, workers with disabilities are still largely underrepresented in most workplaces [27,76], particularly in STEM fields [77]. Further, discussions of accessibility in these contexts often end once accessibility services or assistive devices are provided, though we know that social factors affect the adoption

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and use of these resources in practice [10,58,83]. To address these issues, we must take a broader but situated view of accessibility. Instead of viewing accessibility as a property of a system that supports the person with a disability, our work and others examines the wider social context in which accessibility is negotiated and co-created among teams with diverse abilities [9,10,49,101,102].

To better understand how mixed-ability teams communicate and coordinate in industry and academic settings, we present an analysis of co-located small group collaboration among Deaf and hearing professionals. In today's technology-rich workplaces, professional teams develop their own workflow and practices over time: some teams engage in brainstorming with sticky-notes and whiteboards, some work side-by-side on a shared computer to debug code, and others use a lively Slack channel to coordinate. This amalgamation of physical and digital tools enables participants to take advantage of different modalities, channels, and platforms that suit the unique needs of their team. We know little, however, about how teams with different sensory abilities appropriate such technologies as part of small group collaboration. In their paradigm-shifting piece about place and space in groupware, Harrison and Dourish [40] state that audio in groupware is "truly shared; we each speak and hear in the *same* audio space. The sound of my voice carries over the audio connection and invades your space; it doesn't stay in a fixed place until you attend to it." What work practices emerge when co-located collaborators have different sensory abilities and no single shared audio space? Further, how do Deaf-hearing teams achieve accessible co-located interaction in the context of technology-rich workspaces?

We report on interviews with fourteen individuals (7 Deaf, 7 hearing) who have collaborated in Deaf-hearing teams. Our participants represent a specific subset of the Deaf community, who use sign language (but may also speak), are highly educated, and work professionally in industry and academia. We supplement interview findings with a video analysis of six sessions of co-located work among Deaf-hearing dyads. While these professionals often interact through sign language interpreters and real-time captioning, there are many instances of small group collaboration in which these services are unavailable, leaving teams to negotiate alternative configurations for successful group work. We focus our analysis on these instances in which no accommodations are available and groups must develop other practices for communication and coordination.

This paper makes conceptual and practical contributions to CSCW. First, our analysis reveals that accessibility in Deaf-hearing teams is a complex process that is learned over time and enacted by all team members. That is, we argue that Deaf-hearing teams create accessibility through their moment-to-moment co-located interaction and emerging team practices over time. As key aspects of creating accessibility, we detail how collaborators learn to attune to each other and improvise with different resources, modalities, and technologies for communication and coordination. Second, our analysis of Deaf-hearing interaction extends a growing body of work on accessibility in mixed-ability teams and provides insights for future groupware for more inclusive workplaces.

2 RELATED WORK

Our analysis of Deaf-hearing teams brings together research on accessibility in teams, the design of assistive technology as groupware, and literature on Deaf communication.

2.1 Accessibility in Teamwork and Collaboration

Prior CSCW research examines small group interaction among diverse team configurations, such as worker-helper dyads with asymmetries in visual knowledge about the task [28] or multicultural multilingual teams [25,26]. Recently, however, researchers have begun to

understand the ways in which small groups with differing physical, cognitive, or sensory abilities collaborate. As a key example, Branham and Kane [9] analyzed the living practices of blind and sighted partners, detailing the ways they coordinate to support each other in co-habitation. Our analysis builds on their analysis of accessibility as a collaborative group practice by examining the ways in which teams create accessibility through the organization of human social action in context. Branham and Kane [10] also detail the 'invisible work' that blind employees do to identify accessibility challenges and solutions in predominantly sighted workplaces. Still other work examines how blind individuals perform navigation tasks with sighted companions [97], shop together [100], and perform real-time visual queries [7], detailing additional contexts in which blind-sighted collaboration occurs.

In addition to studying homes and workplaces, recent work has examined collaboration among mixed-ability teams in educational settings. Zolyomi et. al [101,102] investigated practices of neurodiverse student teams, specifically autistic individuals and their neurotypical peers, in higher education. Their analysis describes the process of small group formation and the challenges students on the autism spectrum experience in expressing their differences and conflict resolution. The present paper extends these ideas on accessibility in longer-term small group collaboration to better understand the dynamics of interaction among Deaf-hearing teams.

2.2 Assistive Technology as Groupware

Recent work has begun to consider the design and use of assistive technology beyond the individual with a disability, and this work positions assistive technology as a form of groupware. An early example is work by Piper and Hollan [80,81], who designed a tabletop system to support communication between Deaf patients and hearing doctors. This work found that providing access to a shared visual workspace reshaped the nature of interaction between the Deaf patient and hearing doctor, leading to increased eye contact between the dyad. Other work considers the social processes of using Augmentative and Alternative Communication (AAC) devices, and designing interfaces to support nonverbal communication and empower the participant with a disability. Fiannaca et. al [22] argued that AAC devices are a form of groupware that should support conversation for everyone involved rather than focusing on throughput and word expression rate. Sobel et. al [87] engaged with people with ALS to explore representations of nonverbal cues in AAC devices via text, emoticons, emoji, avatars, thematic animations, and colored LED clusters. Their findings revealed AAC users' concerns with how these cues are interpreted and unpack how both the person with ALS and their conversation partner are affected by the AAC device.

While assistive technology for Deaf people is an active subarea of HCI and CSCW research, existing work tends to center on a Deaf individual's experience with visual or tactile alternatives to audio content [8,53,84,85] and translations between spoken English, captions [15,56,59], or sign language [55,68], rather than promoting equitable participation in group work. A notable exception is provided by Gugenheimer et al. [38], who assert that assistive technology "should not be seen as 'just' a tool for the Deaf but rather as a collaborative technology" and prompts the next generation of assistive technologies to enable hearing people to sign instead of enable Deaf people to speak. Attending to the social nature of assistive technology helps to reframe assistive technology as a form of groupware instead of as technologies for a single individual. In this vein, our study investigates how Deaf and hearing

teams use shared interfaces, prosthetics, and low-fidelity techniques (e.g., pen and paper) to support interaction and inspire future groupware design.

2.3 Deaf Communication and Teamwork

Given the focus of the present study on Deaf-hearing professional teams, we now turn to related literature from Deaf Studies for background on how Deaf professionals who are bilingual in English and ASL (American Sign Language) engage in predominantly hearing environments. Individuals who identify as culturally Deaf embrace visual communication instead of spoken communication [5,14,23,24,78,79], which affects how a Deaf individual chooses to interact with hearing collaborators. Further, signers have unique ways of interacting in DeafSpace [24], where everyone is expected to use sign language and other forms of visual communication. For example, individuals in DeafSpace often reposition themselves and furniture to maintain sight lines as individuals enter and leave conversations [24]; change signing speed and sentence structure (e.g., Pidgin Sign English [11] combines aspects of ASL and English, and is distinct from "pure" ASL) depending on signing fluency of the addressee [94]; get attention via visual-gestural cues instead of calling names from afar [95]; and use full-body pantomime with classifier handshapes [93,96].

Given the necessity to pre-secure a Deaf addressee's line of sight rather than be in earshot for communication, gaze and visual attention are important in studying Deaf communication. We know from prior research with sighted hearing participants, gaze can give information about turn-taking, show liking, and demonstrate engagement [1,16–18,30,31,60]. For Deaf people, sustained gaze on a speaker signals that the other person has the floor and shifting gaze away from that person can indicate turn requests [2,3,86]. Gaze direction can also be used for deictic reference [3,21] and looking at one's hands can call attention to gestures [20]. But, signers carefully monitor their addressee's gaze to ensure that they too are looking at the gesture or referent [39].

In addition to understanding interaction among multiple Deaf individuals, prior work in Deaf Studies, audiology, and HCI examined Deaf-hearing interaction in mainstream elementary schools [82,91,99], technologies for Deaf students of hearing instructors in lecture-based classrooms [61–64,66,67], automatic speech recognition in Deaf-hearing conversations [6,29,70], and multicultural experiences of families with Deaf children and hearing parents [54]. Toe and Paatsch [91] studied communication between Deaf-hearing elementary student dyads, and report on how face-to-face communication requires partners to recognize communication breakdowns, seek clarification, and "repair" the conversation accordingly. Johnson's ethnographic study [54] revealed the tensions that hearing mothers of Deaf children grapple with as these families are "situated in a unique in-between space—between modalities, languages, and ideologies" of Deaf and hearing worlds. While this work with students and families adds to what we know about Deaf-hearing interaction, there have been very few studies of collaboration between Deaf and hearing professionals (i.e., adults in industry or academia), in which domain-specific knowledge is essential and co-located collaboration occurs in technology-rich workspaces. This is the gap that our analysis aims to fill.

3 PHASE 1: UNDERSTANDING COLLABORATION IN DEAF-HEARING TEAMS

To understand accessibility in Deaf-hearing collaboration, we conducted semi-structured interviews with Deaf and hearing individuals with prior experience on Deaf-hearing teams.

These interviews investigated accessibility as an evolving and collaborative process from both Deaf and hearing perspectives.

Pseudonym	Hearing/Sign Fluency	Professional Background
Mari	Deaf, fluent signer	PhD STEM researcher and former software engineer
Jake	Deaf, fluent signer	PhD student in the social sciences
Josh	Deaf, fluent signer	Software engineer
Pan	Deaf, fluent signer	Software engineer
Sean	Deaf, fluent signer	Software engineer
Chris	Deaf, fluent signer	Undergraduate STEM major
Gabe	Deaf, fluent signer	PhD student in a STEM field
Erin	Hearing, non-signer	UX designer
Jess	Hearing, non-signer	Undergraduate STEM major
Tony	Hearing, beginning signer	PhD student in a STEM field
Dave	Hearing, beginning signer	Master's student in Global Health
Beth	Hearing, fluent signer	American Sign Language Interpreter
Joy	Hearing, non-signer	Faculty mentor in a STEM field
Kaylee	Hearing, non-signer	Undergraduate STEM major

Table 1. Description of interview participants' hearing ability, language fluency, and professional background.

3.1 Method

3.1.1 Participants. We interviewed seven Deaf professionals and seven hearing professionals with experience on Deaf-hearing teams (Table 1). Participants were recruited via the research team's network within academia (n=5), local sign language events (n=2), and snowball sampling (n=7). All participants (in their 20s or 30s) are professionals working in industry or academia, and based in the Midwest or East Coast regions of the United States. Given the nature of snowball sampling, some participants had experience working with others in the study (e.g., Mari regularly collaborates with Tony, Beth, Joy, and Jess).

While some Deaf participants had residual hearing (e.g., through hearing aids or a cochlear implant), all identified as Deaf[1], and stated that they work in predominantly hearing settings and are often are the only Deaf person in their workplace. Given our focus on Deaf-hearing collaboration in professional and academic settings, our interview sample is highly specialized and may not represent the broader deaf, Deaf, and Hard-of-Hearing community. In particular, all Deaf participants achieved Bachelors or Graduate degrees and were bilingual in English and ASL (American Sign Language). That is, in addition to signing, all Deaf participants were able to voice on their own (i.e., speak) and write or type in English. All had varying experiences with different communication strategies (e.g., lipreading, sign-supported speech) and accommodations (e.g., sign language interpreting, real-time captioning).

[1] As bilingual Deaf professionals in predominantly hearing workplaces who also engage with their local Deaf communities outside of work, our Deaf informants identify as culturally Deaf. Lowercase "deaf" and uppercase "Deaf" have different connotations, as described by Ladd [65]: "The lowercase 'deaf' refers to those for whom deafness is primarily an audiological experience. It is mainly used to describe those who lost some or all of their hearing in early or late life and who do not usually wish to have contact with signing Deaf communities, preferring to try and retain their membership of the majority society in which they were socialised. 'Deaf' refers to those born Deaf or deafened in early (sometimes late) childhood, for whom the sign languages, communities, and cultures of the Deaf collective represents their primary experience and allegiance, many of whom perceive their experience as essentially akin to other language minorities."

All hearing participants communicated in English. Some started learning sign language during their Deaf-hearing team experiences (indicated in Table 1).

3.1.2 Procedure. We conducted interviews in different modalities depending on the participants' communication preferences, including spoken English, typed English, and ASL. An ASL interpreter was made available for mediating communication between the researcher and Deaf participants, as needed. Interviews were 60-90 minutes and followed a semi-structured format to allow participants to describe specific team experiences and for additional topics to emerge. Participants were first asked to provide context about their work, collaborative practices, and team roles, and then to describe how they chose to interact during different tasks. They discussed one-on-one collaborations (e.g., tutoring for a software engineering class, meeting with primary advisor), small teams (e.g., study group for a Linguistics class), and large-scale collaborations (e.g., research projects spanning multiple labs). Participants described their rationale for switching between auditory, visual, and gestural modalities for specific situations the team encountered over time (e.g., side-by-side on a computer versus giving a presentation to a large group). They also elaborated on creatively repurposing everyday technology for Deaf-hearing collaboration (e.g., text editors, mobile devices, pen and paper, whiteboards, chat platforms).

3.1.3 Data Analysis and Positionality. Our iterative process of analysis is informed by constructivist grounded theory method [12,13], which relies on constant comparison of data to data and data to emerging concepts. Interviews were documented in a format dependant on their modality (audio files for spoken or interpreted interviews and text files for typed interviews) and real-time handwritten notes. In the section below, we italicize quotes spoken by informants or a sign language interpreter verbalizing for a Deaf participant. Quotes typed by informants are in `monospace font`. Context and gestures necessary to make meaning of the quote are included in parentheses.

Initial open coding identified diverse communication strategies (e.g., lipreading, writing on paper, typing, sign language interpreting), context-dependent reasons for choosing one strategy over another, the role of technology, and how communication practices evolved over time. We updated the interview guide (see Appendix) throughout the data collection and analysis process to better understand emerging ideas and probe open areas of questioning. Through our iterative process of analytic memoing and constant comparison of data to emerging themes and concepts, we began to identify processes through which Deaf-hearing groups and dyads created accessibility, both during initial interactions and over the long-term.

As part of our analytic process, we attend to how we construct our actions and reflect on our positionality as researchers. Both of the authors are hearing, have training in computer science and the social sciences, and are prior students of Deaf mentors at predominantly hearing academic institutions. The first author is actively learning ASL and regularly attends local ASL events (e.g., coffee chats, board game night, civic tech meetups). She has also participated in a sign language immersion program to learn more about ASL and be "voice-off" in DeafSpace [24]. This participation in Deaf community events provided additional opportunities to understand Deaf-hearing teams and how their communication evolves over time.

3.2 Findings

Our analysis of interview data reveals that accessibility in co-located interaction among Deaf-hearing collaborators is a multimodal process learned over time and enacted by all team members.

We will briefly provide context for status quo accommodations for Deaf-hearing interaction, as Deaf-hearing teams described different experiences with and without these services. Sign language interpreting and real-time captioning (CART) are two common accommodations for Deaf professionals. Although companies and academic institutions in the United States are legally required by the Americans with Disabilities Act to provide accommodations upon request [92], each Deaf-hearing team develops different strategies for navigating workplace interactions. In particular, we learned that Deaf-hearing teams relied on a myriad of communication strategies (e.g., speaking, lipreading, writing, and typing) to support impromptu interactions when interpreting or CART services were not present. We focus our analysis below on how Deaf-hearing teams learn to collaborate – and thus create accessibility – without primarily relying on these accessibility services.

3.2.1 Navigating Initial Expectations for Interaction. Many hearing informants described their first, if not only, experience with Deaf collaborators. Kaylee (hearing undergraduate STEM major), describes how a software engineering professor paired her with a Deaf tutee and told Kaylee in advance that the student was Deaf. Kaylee did not know what to expect for her first meeting, *"Honestly I had never interacted with a Deaf person before so I was wondering like 'How are we going to communicate? There's not going to be a translator there or anything.'"* She then recalls her experience during the meeting, *"I remember being particularly shocked, maybe because of my ignorance, that she …introduced herself verbally and she was able to read my lips and I was very impressed by that."*

Kaylee is not unusual for being "*particularly shocked"* when meeting a Deaf colleague for the first time and "*impressed"* when they follow spoken conversation norms. While being in a Deaf-hearing team stands out to Kaylee and other hearing informants as a unique one-off experience, this is the everyday life and reality of Deaf professionals. Our Deaf informants described being the only Deaf person in their workplace. Mari (Deaf PhD STEM researcher and former software engineer) describes how *"clueless hearing people"* respond after meeting Deaf professionals for the first time, *"Some hearing people are really good about adjusting to work with Deaf people and some hearing people are terrible at it."* She elaborates on the latter, *"If they try to adjust, they actually make things worse because they start to slow down their speech a lot. They drop to super simplified English vocabulary. I don't even know if they realize they're doing it and… (I remind them) 'We're still having a graduate level discussion. Please use polysyllabic words.'"*

These initial expectations and reactions to communication are rooted in Deaf and hearing professionals' different upbringings and lived experiences in the predominantly hearing world. While most hearing professionals lack prior experience interacting with Deaf peers, many Deaf professionals grew up in entirely hearing families and their initial exposure to spoken or signed communication varied. Some informants learned sign language early in life and others learned in adulthood, largely depending on whether parents exposed them to signing with the Deaf community. All of our Deaf informants underwent speech, lipreading, and hearing aid training at a very young age. This allows the Deaf individual to converse following the hearing collaborator's expectations to speak and hear. Jake (Deaf PhD student in the social sciences), explains how he navigates speaking norms and hearing people's expectations, depending on their relationship in addition to what he knows about them. He says he chooses `"the optimal modality for our current communicative situation."` During first encounters, however, he says: `"i will almost always voice unless i really dont want to… i often speak to make it easier for the other person [to] understand me… as comm is faster -- thats what they assumed would happen."`

Although Jake is attempting to make interaction easier on his hearing conversation partner, lipreading is non-optimal due to the low accuracy and mental exhaustion. Lipreading typically has 30% to 45% accuracy and depends on context clues and numerous guesses to infer what the speaker meant [4,19,50]. Additionally, to support lipreading, hearing collaborators must maintain eye contact while speaking with Deaf teammates. Both Deaf and hearing informants mentioned that this requires a conscious effort and constant reminders at first, as hearing people are accustomed to speaking freely without needing to secure their addressee's eye gaze. Nevertheless, Jake states that going with the "assumed" spoken norm with strangers can be faster for that specific interaction. He also explains that the initial decision to use one's voice or go "voice off" can set precedent for future interactions in the workplace. He says this "establishes our interaction pattern -- its really interesting how strong that is too -- like even if i switch later theres still a sense of default of reverting to whatever we first communicated with." Our Deaf informants were mindful of setting a "default" for communication with collaborators, which they felt was defined by their first experience interacting with that person.

3.2.2 Negotiating Accessible Communication Practices. Given the lack of widespread awareness about accessibility, Deafness, and visual communication in the predominantly hearing workplace, our Deaf informants describe the "burden" and social cost of negotiating accessible communication strategies as collaborations form.

As our informants described and others have found with different groups [10,101,102], a major facet of creating accessibility involves educating others. As new collaborations took root, Deaf informants described how they taught hearing colleagues, staff, and bosses about how to communicate with Deaf individuals, with and without accommodations. Gabe (Deaf STEM PhD student) describes the ongoing process of teaching his primary advisor about accessibility, "He knew I had a hearing loss of some kind before meeting me… He was surprised that I could speak… it's a process of onboarding him to various pieces of the accessibility request process." Considering the extensive collaboration that occurs over time between a primary faculty advisor and doctoral student, it is not surprising that Gabe is willing to invest time and effort in educating his advisor about accessibility practices.

While the example with Gabe was concerned with accessibility infrastructure and educating others in his workplace, Mari (Deaf PhD STEM researcher and former software engineer) explained the one-sided mental-physical burden of engaging in spoken co-located interaction throughout the day. Mari explained that when Deaf professionals speak and lipread, they *"create access via their (one-sided) labor…"* and emphasized an importance to acknowledge *"the cost of access and who bears it."* Mari and other Deaf informants implied that spoken communication strategies typically have a higher accessibility creation cost than visual communication strategies for Deaf professionals. For example, Mari pays the cost of accessibility by lipreading with hearing colleagues, as this will *"kill her cognitive capacity for the day."* Although Mari is excellent at lipreading and speaking, she occasionally asks hearing collaborators to type or write things to her when lipreading is not optimal for the current situation. This request may be hit or miss, as Mari said that many hearing collaborators are "*clueless*" about how to interact when she tells them she is Deaf. As an alternative to speaking, Mari often leverages the familiarity her collaborators have with typing and writing, and asks to type or write back and forth while sitting face-to-face. However, Mari describes that co-located text-based interaction can be unfamiliar to hearing collaborators and must be negotiated as a new strategy for in-person meetings. Further, she says that some hearing people

are not willing to *"play"* with communication norms and is mindful of the social acceptability of these interactions.

While Mari describes a common scenario in which the Deaf person is expected to lipread and the hearing collaborator speaks as usual, we learned of other instances in which hearing people actively took on the work of creating accessibility and negotiated new communication practices. Some hearing informants described learning fingerspelling and basic phrases in sign language to support speaking and writing. Others used visual communication strategies (e.g., gesturing, drawing) whenever possible. As another example, Jake (Deaf PhD student in the social sciences) described how a hearing colleague fluent in ASL would step in and provide "informal interpreting" [37] so he could participate in a group conversation with mostly non-signing hearing people. He reflects, "so in general a burden is placed on various ppl (people) to make the convo accessible to me and sometimes I feel a bit uncomfortable since the convo would be much smoother faster w/o (without) me…" Jake feels his presence and differing communication needs are complicating the group activity, as his hearing teammates are putting in effort to communicate in both sign language and spoken language. Alternatively, a non-signing hearing teammate may type what others are saying so Jake is still clued in to the conversation. In these groups, it was not a matter of whether or not Jake was competent enough to follow the conversation; the challenge was that the modality (i.e., spoken language) was not accessible, requiring additional time and effort from hearing collaborators for Jake to participate.

3.2.3 Learning to Embrace Multimodal, Improvised Communication. As part of negotiating new practices for accessible group work, we learned that, over time, our hearing informants expanded their communication skills and began to explore new, improvised ways to communicate with Deaf collaborators. In contrast to earlier encounters which may have relied solely on the Deaf person's lipreading ability, participants described encounters that integrated additional communication modalities and tools as needed. Indeed, participants described being mindful of their partner's experience and fluidly adapting the ways in which they communicate to better support each other.

Kaylee (hearing undergraduate STEM major), elaborating on her experience tutoring a Deaf student for a software engineering course, describes how spoken language was not her only means of communicating, *"We would usually… just try her read[ing] my lips and voicing out what she wanted to say. If that didn't work, then we would write...or sometimes it was easier to just pull out Notepad [the software application] or something on the computer and then [type]."* Kaylee's approach of iterating through lipreading, writing, and typing suggests that effective Deaf-hearing communication relies on resourcefulness with different modalities and acquired sensitivity to the current state of the conversation and collaborators. The technologies that Kaylee and other informants mentioned are ubiquitous among professionals: text editors, chat windows, smartphone screens, pen and paper, and whiteboards. The novelty is in how collaborators, rather than relying on a single modality, learn to fluidly switch and leverage parts of their technology-rich environment to support their unfolding collaboration, particularly when accessibility services (e.g., interpreters, real-time captioning) are unavailable.

While the example with Kaylee above described incorporating and switching between modalities within a single encounter, over time hearing collaborators also learned that communication preferences may change for different types of encounters. Erin (hearing UX designer) describes interactions with her Deaf coworker on a different engineering subteam. This included spoken greetings and short conversations, *"If we were just saying 'hi', we understand each other. I think he can lipread."* Longer conversations about product design

decisions, however, warranted her coworker to cue Erin to type instead, *"I think he didn't tell explicitly but then he'd be like (gestures towards a keyboard)"* As such, Erin understood and followed her Deaf colleague's request to switch from speaking to typing. In another instance, Jess (hearing undergraduate STEM major) described following her Deaf mentor's decisions to speak and lipread in some meetings and have an interpreter present in other meetings.

Mari (Deaf PhD STEM researcher and former software engineer) describes an appreciation for "*Deaf-friendly collaborators*" who are willing to flexibly switch between communication modalities and experiment with new ways of interacting. In describing one such colleague during a multiple-hour meeting, she said, *"[hearing colleague] and I improvise a lot. She might be typing, and I might be talking, but then I might stop talking and then go to a whiteboard and write stuff if I wanna draw something out for her."* Mari also explained that her hearing colleague reflected on how much speech she was using and the taxing nature of lipreading. Later in the meeting her hearing colleague would, *"…pause herself and be like 'Hang on, I'm just going to switch to writing this down.' and so she'll type if we have a computer."* Mari comments that this type of interaction between collaborators and attention to modality switching due to her fatigue and comfort marks a transition from a hearing teammate being *"clueless"* to *"clueful."*

We found that hearing collaborators learned to embrace this flexibility and different ways of communicating as well. Kaylee was fond of writing and diagramming software engineering concepts during her Deaf-hearing collaboration, *"Even if it was time consuming, I really liked this approach of writing the diagrams, and her and I going back and forth. Because I just felt it was... Like, I was talking to her directly rather than having someone else (an interpreter) in between."* This revealed Kaylee's beliefs about communication and sensitivity to the differences between interpreted and direct communication strategies. Similarly, Tony (hearing STEM PhD student who has collaborated with Deaf classmates on STEM and research projects) mentioned, "*With [my first Deaf collaborator], it was an emergent 'learning how to communicate with a Deaf person' in a way that's respectful and inclusive of the fact that they are Deaf and cannot hear.*" Then, after working on several different Deaf-hearing teams, Tony described a shift in his views from "*giving access to verbal communication*" to "*giving access to communication… Making sure we're having a conversation in a shared modality that's comfortable to everyone.*" Instead of reinforcing spoken communication norms and responding to hearing loss as the communication challenge, we found that over time, Deaf-hearing collaborators began to acknowledge and practice both spoken and visual forms of communication, being flexible and choosing what was comfortable for that specific meeting.

While these first-person accounts of collaborative practice highlight the emergent nature of accessibility in group work, we now turn to video data of Deaf-hearing dyads to provide a more nuanced analysis of co-located collaboration.

4 PHASE 2: ANALYZING CO-LOCATED DYADIC INTERACTION

Our interview findings above report on diverse collaborations in different group sizes (e.g., dyads, small groups, research labs, classes) and contexts (e.g., pair programming, tutoring, study group, design reviews). To better contextualize, extend, and triangulate our findings from our interview study, we video recorded and analyzed Deaf-hearing dyads in ongoing collaborations. Taken alongside our interview data, our detailed micro-analysis of dyadic interaction provides a nuanced view of how accessibility is enacted and negotiated moment-to-moment among Deaf-hearing collaborators. Here we focus on interaction when an interpreter or CART is not

mediating communication, as we know much less about how Deaf-hearing collaborators create accessibility without these resources.

4.1 Method

4.1.1 Participants. Six individuals (two Deaf and four hearing) participated in observation sessions (see Table 2). These individuals also participated in the interview study with the exception of Sam and Ella, who are hearing PhD students and proficient in ASL. See Table 1 for language details for other participants. We recruited these individuals by reaching out to participants in our interview study as well as via snowball sampling (i.e., recruiting multiple hearing collaborators of a single Deaf individual). This allowed us to observe a diversity of collaborative practices. These Deaf professionals were bilingual in ASL and English, and all hearing participants were part of active Deaf-hearing collaborations with their respective colleague. Given one author's immersion in field work involving Deaf teams and ongoing collaboration with Deaf colleagues in the academic workplace, one hearing researcher participated in two of the observation sessions. All dyads had worked together and interacted professionally on multiple occasions prior to the session. We focus on Deaf-hearing dyads who already knew each other well and whose work could be easily observed (i.e., academic writing and web development can be done on a laptop without specialized lab equipment). Thus, the video recorded session was not their first time collaborating on the observed type of task.

Session	Participants	Relationship	Observed collaborative task	Typical work environment
1	Jake & Ella	Graduate student colleagues from different universities	Brainstorming for a research study	Team room in social science department or coffee shop
2	Jake & Sam	Graduate student colleagues in same research lab	Exchanging feedback on a research paper	Shared office in university social science department or coffee shop
3	Mari & Ella	Academic mentor and colleague from different universities	Web development; Discussing an assistive technology prototype	Team room or office in computer science department or coffee shop
4	Mari & Beth	Academic co-authors at same college	Web development; Discussing project materials and branding	Team room in engineering college or coffee shop
5	Mari & Tony	Academic co-authors in same university	Discussing theoretical frameworks for a research paper	Team room in social science department or coffee shop
6	Mari & Joy	STEM education consultant and faculty mentor	Planning faculty training workshop and curriculum	Coffee shop and asynchronous discussions via instant messaging

Table 2. Description of observation participants, relationship, collaborative task, and typical work environment.

4.1.2 Procedure. Observations occurred in the participant's workplace or home workspace. Each dyad was encouraged to communicate however they preferred. We made an interpreter available upon request for the sessions; however, only one dyad (session 6) relied on the interpreter. Our analysis below focuses on interaction that is not mediated by the interpreter. We prompted participants to select and continue working on an existing collaborative activity during the observation session. All but one dyad sat side-by-side and shared one computer. One dyad sat across from each other and used their personal computers. The researcher sat to the side, which provided a view of the participants' body movements and workspaces. With participant's consent, we video recorded all observation sessions.

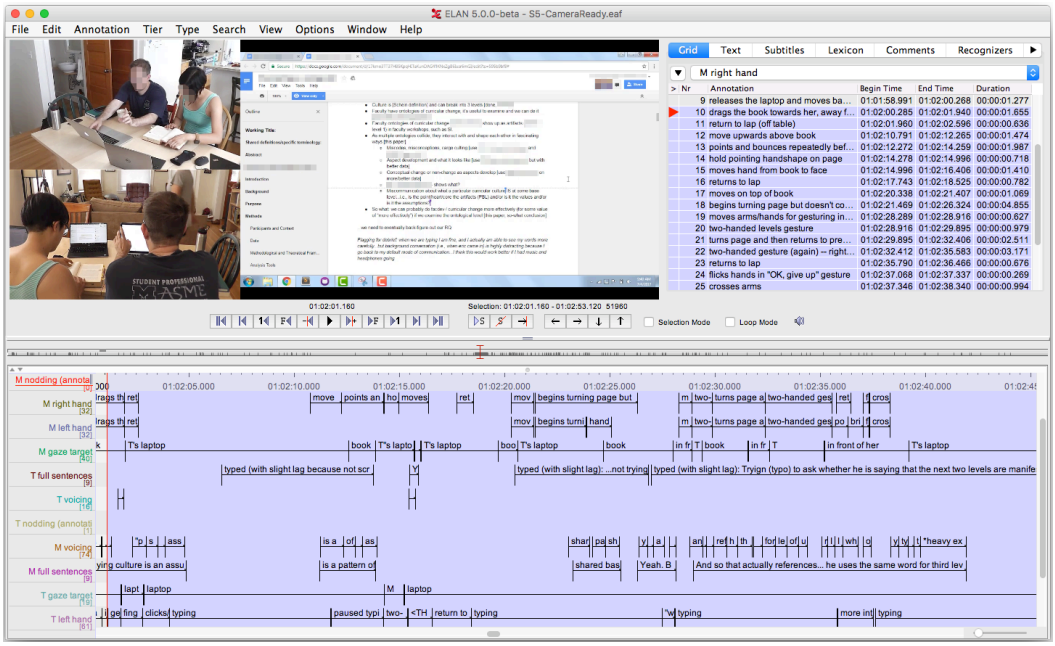

Fig 1. Video analysis in ELAN [98] with multiple video angles, screen capture, and codes for multimodal communication.

We placed a camera in front of dyads to capture facial expressions and body movements, and another camera behind dyads to capture above-screen gestures and computer peripheral usage. We recorded laptop screens with participant consent. Afterwards, the researcher asked follow-up questions about what occurred during the observed meeting.

4.1.3 Data Analysis. Our analytic perspective understands communication as embodied, multimodal, and situated [32–34,41,46–48,89,90]. Thus, we analyze the organization of human social action by attending to how different modalities are instantiated in context and combined to establish meaning as interaction dynamically unfolds. After reviewing the recordings, we began analysis by coding and memoing the ways in which dyads combined and switched modalities (e.g., speaking to typing to signing) throughout a meeting. We created fine-grain annotations in ELAN [98] for different modalities (example in Figure 1, with codes for the activities of participants' left hand, right hand, eye gaze, spoken language, and nodding), using video transcription techniques to understand specific aspects of interaction [41] alongside written analytic memos.

In addition to the detailed micro-analysis, we also coded phenomena that expanded upon and better contextualized our interview findings regarding communication strategies, context-dependent reasons for choosing one strategy over another, and the role of technology. In particular, we coded how dyads secured their Deaf partner's visual attention before beginning their conversation turn, requested clarification that prompted a switch in communication strategies and/or repetition or repair, and used technology for both conversation and work content. Our video analysis focuses on dyads to understand how partner-specific adaptations and communication strategies between peers unfold moment-to-moment, although we acknowledge that this will differ with other groups with more members or other types of power relationships (e.g., teacher-student versus peer-to-peer).

4.2 Findings

Our analysis of video data extends findings from our interview study by providing a nuanced view of creating accessibility in co-located interaction. For Deaf-hearing dyads, this involves learning to understand the demands on visual attention for both language and workspace activity, and supporting collaborative meaning-making through multimodal communication strategies.

4.2.1 Learning to monitor and coordinate visual attention. While hearing collaborators may initially verbalize while gesturing towards or acting on the workspace, assuming their partners can look while listening, Deaf-hearing teams quickly realize the demands on a Deaf participant's visual attention. The lack of a "shared audio space" [40] for spoken conversation means that language must be expressed visually, making it difficult for a collaborator to simultaneously attend to visual language forms (e.g., lip shapes, signs) while they or their collaborator are gesturing over or editing the workspace. That is, there is a spatial separation (i.e., not in the same field of view) between where language is produced (e.g., one's lip shapes) and the content that language is modifying (e.g., pointing to a book on table, highlighting a line of code). One way to adapt to this spatial separation and create accessibility is to decouple speaking and gesturing (e.g., first speaking then gesturing or vice-versa) and constantly monitor teammates' visual attention and understanding.

To illustrate this decoupling behavior, we present a detailed example of Mari (Deaf PhD STEM researcher and former software engineer) and Tony (hearing beginning signer and STEM PhD student). Mari is guiding Tony through a book chapter after suggesting to Tony that they use theories about culture from that chapter in the paper they are co-authoring. Tony has no prior knowledge of these theories and attempts to ask clarifying questions. They are sitting side-by-side with the book in front of them and Tony's laptop open nearby. This seating arrangement allows them to easily look downwards to engage with the book or other artifacts on the table. There is also enough space for Mari and Tony to turn to each other as needed to look at facial expressions, gestures, and signs.

Fig 2. Tony fingerspells 'C'; Mari infers the word and verbalizes.

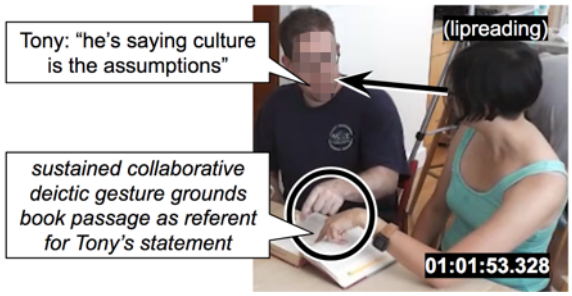

Fig 3. After they gesture on the book and Tony re-secures Mari's gaze, he relies on Mari's lipreading ability when speaking.

In Figure 2, we see Tony (left) and Mari's (right) sustained mutual gaze while Tony is fingerspelling (using ASL's signs for the English alphabet). Here, Tony creates the handshape for the letter "c". Mari quickly guesses that Tony is trying to fingerspell "culture" but does not yet know what is he asking. What is interesting here is that Mari is able to verbalize while looking at Tony's "sign space", or the physical space encompassing the signer's face, handshapes, and hand-arm motions around the torso. On the other hand, when Tony uses a visual communication strategy such as fingerspelling, he has learned that he must pre-secure

and sustain Mari's gaze, although the Deaf partner breaking gaze can be a signal to end the conversational turn [2]. Mari's gaze on Tony's sign space prevents her from looking at other visuals that could be referenced or acted upon (e.g., the book or their shared Google Doc). Trying to finish his question, Tony switches to speaking and relies on Mari to lipread (Figure 3). Tony is asking about a specific passage in the book, to which he points, followed by Mari pointing to the same location. While Tony looks at the book as he speaks, Mari's gaze is fixed on Tony. Yet, her sustained pointing gesture towards this passage confirms that she is attending to both what Tony is saying and the referent of his speech (i.e., what the book asserts about culture). As part of creating accessibility in this instance, the dyad is learning to maintain and redirect each other's visual attention (from handshapes to lips to the book) and adapt to the demands of visual communication, which is strenuous for both parties and initially unfamiliar to hearing collaborators.

What we observe with Tony and Mari resonates with the practices hearing participants shared in our interview study. For example, Kaylee (hearing undergraduate STEM major) described coordinating pen and paper, spoken language, and eye contact with her Deaf tutee, "*I would write down 'F E' and then look at her and be like 'frontend' so she could read my lips and then continue (writing and drawing) the diagram, stop her, and go back to her.*" Kaylee describes being aware that her collaborator is not lipreading when attending to the printed diagram, "*but I wouldn't do both (speaking and drawing) at the same time because I feel like [Deaf colleague] would have been very overwhelmed like 'Where am I supposed to look at?!'*" As another example, Tony described his Deaf-hearing study group experiences prior to meeting Mari. He explained that he had to be intentional about the timing of his speech and gestures to ensure his Deaf classmate processed what he was saying in the context of his embodied actions in their visual workspace, "*I had to really be conscious… a good component of what she was doing was lipreading. And so if I pointed at something, I had to stop talking. Give her a second to look at that… process it… Once she looked back up at me, we can continue talking.*" The work of monitoring and coordinating visual attention illustrated above and described by Kaylee and Tony demonstrates the moment-to-moment attunement that is integral to creating accessibility in co-located interaction.

4.2.2 Aligning visuals with environmentally coupled gestures. Another emergent practice of Deaf-hearing teams involves layering gestures and signs over the visual workspace. Instead of redirecting visual attention towards language and then towards the workspace, collaborators would put both in the same field of view by visually aligning one's body with the content they were modifying, creating environmentally coupled gestures [35]. Consider Figure 4, in which Mari (Deaf, PhD STEM researcher and former software engineer; left) and Ella (hearing intermediate signer and STEM PhD student; right) discuss a prototype web application. The dyad is sitting side-by-side while looking at a shared laptop. Mari and Ella are having a typed conversation an hour into the meeting. Although Ella is right-handed and the dominant hand is typically used for one-handed signs, here she uses her left hand and moves it into Mari's line of sight as she signs "yes" (a nodding fist) in response to what Mari is typing. Ella understands that Mari's visual attention is on the laptop and moves her body into Mari's field of view. Ella's

Figure 4. Ella signs "yes" with her left hand so it is in Mari's field of view and does not disrupt Mari's typing.

awareness of visual communication in this situation allowed Mari to continue looking at her workspace while also attending to her partner.

We learned through our interview data that this visual alignment strategy also occurs with horizontal shared workspaces and writing-drawing modalities. Jake (Deaf PhD student in the social sciences), described his experience writing, drawing, and gesturing on a tabletop whiteboard during an academic quarrel with a non-signing hearing colleague about how the mind processes language. Jake described how "`[hearing colleague] would write out text + arrows + brain pictures and i would write over it, gesture back to the text, etc.`" Instead of attending to language and then the workspace sequentially, participants learned to layer communicative gestures on the material workspace to facilitate communication.

4.2.3 Aligning conversation and content through proximal text fields. The complexities of communicating about domain-specific concepts and the pervasiveness of text-based technologies gives way to another communication strategy. In our observations, we learned of dyads repurposing a variety of text fields to support communication. That is, dyads opportunistically used command lines, browser bars, plain text files, Google Docs, and inline comments in text editors for conversational purposes. While many teams also used dedicated chat applications, any area that accepted text input was a site for conversation to occur.

As one example, and part of the same encounter between Mari and Ella described above, the dyad conversed via inline comments embedded in a JavaScript prototype. Ella types "`// Are you familiar with callbacks`" as an inline comment but also as a question directed to Mari. This instantiates a "chat space" embedded in the script that Mari and Ella will regard as conversational and not part of the JavaScript code. This creates accessible visual communication on the screen that is already in both Mari and Ella's field of view, so they do not need to reorient their bodies away from the workspace to look for language. Further, given the need to present communicative acts both spatially and temporally close to the content it modifies, Ella types her question-in-comment at the end of the line of code with a callback function. Mari responds by verbalizing, "*Um... conceptually. Remind me.*" Ella then produces an emblematic thumbs-up gesture to Mari before resuming the typed explanation in the same inline comment. Our interview data again provide further instances of this behavior. Kaylee (hearing undergraduate STEM major) described an example of using inline comments when discussing code with her Deaf tutee because, *"I don't want to say [it was] impossible but it was just too hard to get her to read a line of code and then look at me and then go back."* Additionally, the spatial proximity of conversational inline comments to the code of interest enabled clarification requests. Kaylee said, *"I would write the comment and if she understood she would be like 'Oh okay.' But if she didn't get something, then she would like add something else to the comment at the end [or] she would be like 'oh, line 15' and then look at me and try to ask me the question."* While using inline comments and other fields as a chat space was useful, participants faced challenges with learning to coordinate turn-taking with these new practices.

4.2.4 Learning to coordinate turn-taking through visual cues. The myriad of different modalities dyads use to communicate (e.g., sign, speech, gesture, text, writing) introduce new complexities to how they coordinate turn-taking through visual cues. Continuing the example of Jake (Deaf PhD student in the social sciences) writing and gesturing over diagrams on a tabletop whiteboard, we asked how Jake and his colleague knew when to look at the table versus look at each other. Jake explained that they watch each others' bodies, "`if they are writing i look down and i can see their lower body… sometimes if someone writes something and the other person looks over it or writes something back,`

the first has to wait to say something." Jake elaborates on how they sustained awareness during turns in addition to transitions between turns, "If they were writing i was trying to read what they were writing (and of course I knew immediate[ly] when they were done writing)" and explained how turns could also overlap as long as they were not trying to write on the same place, "(with a marker for each of us) it was fine bc (because) we sometimes would both write, then read each others comments after at the same time." As this example illustrates, participants learned to navigate turn-taking by maintaining an awareness of not only a collaborator's gaze but also their body position and visual cues that indicate they are writing or preparing to write.

In other situations when one collaborator is typing and the other is speaking, dyads must cue to each other to manage both visual attention and the conversation floor. An example of this occurs later in the session between Mari (Deaf PhD STEM researcher and former sfotware engineer) and Tony (hearing beginner signer and STEM PhD student). We observe Tony grab his laptop and type a question in a shared Google Doc with their meeting notes. As Tony types, Mari comments verbally on what he is typing. While continuing to speak, she breaks eye contact with the screen and begins to leaf through the book on the table between them, perhaps assuming Tony can still understand her as he types, since he is hearing and does not need to look at her in order to understand what she is saying. However, Tony quickly flings his left hand towards Mari and positions his hands on the laptop keyboard as if to signal that he would like to finish typing his question. Since Mari is Deaf, and currently facing away from him (looking at the book), Tony uses a visual cue (rather than a verbal or auditory cue) to get Mari's attention and signal her to stop. Mari continues to speak, perhaps still thinking that Tony can understand her. Tony then tries again to interject with a more strongly defined open palm, hand up gesture, which clearly signals to Mari that Tony wants her to stop talking and wait. Mari then leans back in her chair and voices, *"Okay, you can't type and listen at the same time,"* and lets out a deep sigh. As we illustrate here, these dyads must learn and negotiate an organization of action that establishes new norms around turn-taking and managing visual attention in order to create accessible group work experiences.

5 DISCUSSION

Drawing on interviews with and observations of Deaf and hearing collaborators, this paper makes conceptual and practical contributions to CSCW. First, we argue that accessibility in co-located cooperative work is an emergent group practice that is created by all members of the team, both in the moment and over time as collaboration practices evolve. Second, we contribute design insights for future groupware to support Deaf-hearing teams in predominantly hearing workplaces.

5.1 Accessibility as an Emergent Group Practice

Rather than conceiving of accessibility as a service or feature of a system, our work and that of others [9,10,102] conceptualizes accessibility as a collaborative practice that is negotiated by all members of a group and situated in particular social contexts. This theorizing about accessibility highlights the need for a more nuanced look at both the social and material aspects of how accessibility is created during co-located work interactions, which is the aim of the present paper.

As others have noted [9,10,102], accessibility in mixed-ability teams involves negotiating social norms and expectations for interaction. Our analysis reveals that Deaf and hearing

professionals enter their collaborative experiences with different expectations for communication, which may cause initial awkwardness or "shock" during first encounters. Although hearing professionals generally expect to speak during in-person meetings, Deaf professionals make decisions to use their voice, lipread, sign, or some combination depending on the situation, relationship, and other contextual factors. This decision can set precedent for future interactions, surprise hearing people who may not have experienced interpreted or "voice-off" conversations, and also reflect a person's decision to explicitly present (or not present) themselves as Deaf. This parallels how Zolyomi et. al [101,102] report on how Autistic individuals in neurodiverse teams take into account "freedom from stigma, individual comfort, social comfort, and team cohesion" when "balancing tensions between personal and group preferences." For example, while signed communication is often more comfortable for Deaf signers, our informants were wary of whether or not their hearing teammates would be willing to communicate in ways that differ from the spoken norm (e.g., typing while meeting face-to-face) and the social cost this may incur. As such, Deaf professionals may sacrifice accuracy and comfort by choosing to lipread instead of burdening their hearing collaborators to change their behavior. This social cost, however, will likely differ depending on the setting and relationship (e.g., domestic partners [9]).

When we view accessibility as a co-created, emergent group practice, this shifts the focus of analysis away from the individual's disability and attends to how everyone participates in this process. Although Deaf individuals do much of the work of educating others and advocating for resources, over time hearing collaborators also learn how to share the "burden" or social costs of creating accessibility. Some hearing collaborators learn basic sign language or bring an extra keyboard for typed side-by-side conversation. Others who are fluent in sign language will step in and offer impromptu sign language interpretation. We can observe similar themes in how other mixed-ability groups share the burden of creating accessible interaction: AAC users adapt the pacing, volume, and pronunciation [57] of their AAC device's voice to support interaction with family members and friends; blind-sighted co-workers must manage tradeoffs in listening to a screen reader and their sighted teammate when both were voicing at the same time [10]. As Fiannaca et. al [22] argue, when we view assistive technology as a form of groupware, the focus shifts from optimizing for language throughput to providing awareness for the entire group. As such, mechanisms for awareness and how groupware should function must be explored for various social relationships (i.e., groupware for life partners may differ considerably from that for co-workers) and combinations of abilities (i.e., groupware to help Deaf-hearing teams manage the visual channel versus groupware to help blind-sighted teams manage the audio channel).

To extend this theorizing of accessibility as co-created through interaction, we turn to Goodwin's notion of 'reflexive awareness' [32]. Goodwin describes reflexive awareness as a crucial property to the organization of action. This involves ongoing analysis of how a recipient is positioned to co-participate in the interaction and reorganizing one's own actions in terms of what the co-participant is doing. The present case of Deaf-hearing collaboration demonstrates that learning to analyze each other to determine how to participate in a way that enables everyone to contribute to the conversation (as addressors) and engage with others' conversation turns (as addressees) is a key aspect of creating accessibility. Collaborators constantly monitor each other's eye gaze and readily use different modalities (e.g., speaking, gesturing, signing) and available technologies (e.g., text editors, pen and paper, IDEs). Goodwin [32] describes this process as an aspect of reflexive awareness: "Not all of these resources are relevant and in play at any particular moment. However, the ability to rapidly call upon alternative structures from a

larger, ready at hand tool kit of diverse semiotic resources, is crucial to the ability of human beings to demonstrate...reflexive awareness." Echoing the notion of reflexive awareness, Deaf informants described "*Deaf-friendly*" hearing collaborators as those who can spontaneously switch and blend modalities depending on the current task, communication preferences, and available resources. With reflexive awareness as an ideal for mixed-ability teams, we see an opportunity for groupware technologies to better support multimodal conversational awareness and coordination.

5.2 Opportunities and Insights for Groupware Design

Building from the notion of access technology as groupware and the goal of supporting accessible multimodal communication, we consider three directions for future system design.

5.2.1 Interlacing of text chat space and content space. Our informants practiced reflexive awareness as they rapidly called upon resources in their environment – such as opportunistically typing in text fields or inline comments, writing on paper – to communicate with their Deaf or hearing colleague during work meetings. For example, our informant Kaylee (hearing undergraduate STEM major) and her Deaf tutee wrote in the margins next to a printed figure or paragraph, used an inline comment in a code editor to ask about that line of code, and typed conversation into text fields on any open software application (e.g., browser bar). Building on this practice, future groupware systems could better support this embedding and alignment of text chat with visual content. Existing systems, such as commenting features in Word and Google Docs as well as Zyto et. al's NB system [103], allow collaborators to comment in the margins while reading. While these systems render conversational text in ways that are spatially close to the content of interest, they do not account for the rapid turn-taking of tightly coupled work or the ephemerality of some chat and desired permanence of other information. Future interfaces could blend features of instant messaging (e.g., scrolling chat history, text color-coded by user, typing status indicators) with document annotation (e.g., alignment of context and content, visual effects to show contributor activity) to better support synchronous collaboration around a shared visual workspace.

5.2.2 Recording and replaying communication histories. Chat conversations and annotated artifacts that are produced during group work are typically saved on separate platforms rather than integrated into one another. Our informants often revisited chat histories and email threads to double check details, follow up on discussions, or find answers to previous questions. Given that Deaf-hearing teams will embed, align, and layer text with content across different modalities and platforms as they practice reflexive awareness in the moment, we see an opportunity for future systems to save artifacts that preserve these alignment and layering relationships. We see this as an extension of the "physical wear" metaphor introduced in Hill and Hollan's seminal work on Read Wear and Edit Wear [45], which explored how to capture and visualize the spatial "memory" and natural traces of user activity on a document with attribute-mapped scroll bars. In a similar way, we see potential in designing "conversational wear" that visualizes and links conversation histories that occurred around and in various parts of a document.

5.2.3 Gesture and sign language overlays. Another strategy Deaf-hearing dyads use to create accessible communication around a shared visual space is to layer gestural communication over visual artifacts. As part of reflexive awareness, Deaf-hearing teams learned to align their gestures and body orientation with workspace visuals (e.g., using a grouping hand gesture to refer to several lines of code, gesturing over a diagram). We observed an example of this

gestural alignment with Ella (hearing intermediate signer and STEM PhD student) and Mari (Deaf PhD STEM researcher and former software engineer), where Ella signed "yes" with her left hand in Mari's line of sight such that it was visible but did not disrupt Mari's typed conversation turn. A different example is when Jake (Deaf PhD student in the social sciences) would gesture over the tabletop to communicate with his hearing classmates after making notes and arrows on the workspace. Whether this be for iconic gestures (e.g., a "thumbs up"), basic phrases in sign language, or deictic gestures (e.g., pointing to part of the screen), the person gesturing purposefully moved their body in front of the visual content and into their collaborators' line of sight. Semi-transparent video feeds such as ClearBoard [51,52] and FaceTop [75,88] allow for this layering of gestures, eye gaze, facial expressions, and other familiar embodied cues to be blended together on screen, instead of seeing the gestures physically above the screen. While a promising direction, additional considerations and constraints, such as arm reach, timing, and pre-securing the gaze of the addressee, must also be taken into account for communication to be successful. In contrast to the previous insight of embedding chat within content, gestural communication and sign language is not competing for screen space or filling up the margins, but is ephemerally "layered" on top of the workspace.

5.3 Limitations and Future Work

We see future work opportunities in continuing to explore how accessibility is created in different work environments, team configurations, and domains. Our study focused on highly educated bilingual Deaf adults fluent in English and ASL, who are currently a minority in the predominantly hearing professional workplace. The Deaf informants in our study chose to speak or sign depending on their preference and context. However, some Deaf individuals may be strictly "voice-off" and thus must create accessible communication with their collaborators without using any speech. Furthermore, our video analysis provided a nuanced understanding of Deaf-hearing dyads. Future work could also explore how medium to large teams create accessibility (e.g., turn-taking practices in a group of five students will differ from a dyad's turn-taking practices).

One limitation of our study is that we did not have the opportunity to interview or observe Deaf-hearing teams from the beginning of their relationship as collaborators. All of our informants had already been collaborating long enough to develop awareness and adaptations for communication. We explicitly asked in interviews about how informants' perspectives and communication practices evolved over time and were able to report these findings from their retrospective responses. However, there is an opportunity to gain a deeper understanding of the perspectives, needs, and challenges of Deaf-hearing teams at the start of their collaboration.

6 CONCLUSION

Our analysis of interaction between Deaf and hearing professionals provides a novel instance of the co-creation of accessibility in mixed-ability teams. While hearing collaborators primarily speak and expect others to look at the workspace while listening, Deaf-hearing teams must negotiate new strategies for communication and coordination. The lack of a shared audio space requires these teams to meet at the in-betweens of Deaf culture's visual communication norms and the predominantly hearing world's spoken communication norms. As such, teammates navigate their different experiences with modalities and put in a shared effort to make collaboration accessible. Teams learn to adapt to their particular partners' communication preferences and develop strategies to manage the demands of visual communication in complex

visual workspaces. Additionally, building upon recent work that embraces accessibility as groupware, Deaf-hearing teams inspire new tools to support inclusive co-located collaboration. Our research paves the way for additional empirical research and multimodal interfaces in pursuit of providing equitable opportunities for professionals with disabilities.

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A SEMI-STRUCTURED INTERVIEW GUIDE

Questions for both Deaf and hearing informants:

- What experiences have you had in Deaf and hearing teams?
    - Probe for: Profession or academic major, Group size, Duration of team relationship, Power dynamic, Project topic and tasks
- How did you set up your meeting workspace? (Provide pen/paper, ask them to draw a top-down view of their workspace/workplace, and then explain in detail.)
- What are you and your teammates' communication strategies and preferences? How do your communication preferences change with the person, task, and place?
    - Probe for: Do you communicate differently in work meetings than in informal/social settings?
    - Probe for: Meeting someone for the first time, Long-term friends, Acquaintances, Strangers, Boss or research mentor, 1:1 meeting, Group meeting
- How did/does your team decide to communicate?
    - Probe for: Speaking, Signing, Typing, Writing, Drawing, Gesturing
    - Probe for: How do you use technology to communicate?
    - Probe for: Did your team(s) use assistive technology and accommodations? If so, when and how did that impact your communication experience?
    - Probe for: How much did you prepare in advance for communication? (Accommodation logistics, Sending interpreters materials and vocabulary lists in advance)
- How did your communication change over time?
    - Probe for: How did you adapt to each other in the team?
    - Probe for: Is it a shared effort? Or imbalanced effort?
    - Probe for: Are these adaptations unique to that team or something you do with other collaborations as well?
- How do you communicate when you have to work around a [shared visual workspace, e.g. computer, whiteboard, or other platform mentioned in interview thus far]? What do you do differently with a hearing person than with a Deaf person?
- When is Deaf and hearing interaction difficult? What makes it easier?
- What would you have done differently in retrospect? How would you do this in the future?

Questions specifically for hearing informants:

- When did you know and how did you realize your collaborator was Deaf?
- Was this your only experience collaborating with Deaf people or people with disabilities more broadly?
- How did you feel the space was different when your Deaf colleague(s) were in the room versus when they weren't in the room?

Questions specifically for Deaf informants:

- Do you prefer to voice or not voice with hearing people? Why?
- Are you usually the only Deaf person in the room at work?
- Are you involved in the local Deaf community?
- Do you teach others about accessibility and Deaf culture? If so, how?
- What do you do when you know a work or social situation is going to be inaccessible to you?
- What is DeafSpace to you? When do you meet with other Deaf people?
- Do you identify primarily as deaf, Deaf, or Hard-of-Hearing? How has this changed over time?

REFERENCES

[1] Michael Argyle and Mark Cook. 1976. *Gaze and mutual gaze.* Cambridge University Press, Cambridge.

[2] Charlotte Baker. 1977. Regulators and turn-taking in American Sign Language discourse. In *On the Other Hand: New Perspectives on American Sign Language.* Academic Press, 215–236.

[3] Charlotte Baker and Carol Padden. 1978. Focusing on the nonmanual components of American Sign Language. In *Understanding Language through Sign Language Research.* Academic Press, New York, 27–57.

[4] Steven Barnett. 2002. Communication with Deaf and Hard-of-hearing People: A Guide for Medical Education. *Acad. Med.* 77, 7 (2002), 694–700.

[5] Dirksen L. Bauman and Joseph M. Murray. 2009. Reframing: From Hearing Loss to Deaf Gain. *Deaf Stud. Digit. J.* 1 (2009).

[6] Larwan Berke, Christopher Caulfield, and Matt Huenerfauth. 2017. Deaf and Hard-of-Hearing Perspectives on Imperfect Automatic Speech Recognition for Captioning One-on-One Meetings. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '17), 155–164. DOI:https://doi.org/10.1145/3132525.3132541

[7] Jeffrey P Bigham, Chandrika Jayant, Hanjie Ji, Greg Little, Andrew Miller, Robert C Miller, Robin Miller, Aubrey Tatarowicz, Brandyn White, Samual White, and Tom Yeh. 2010. VizWiz: Nearly Real-time Answers to Visual Questions. In *Proceedings of the 23rd Annual ACM Symposium on User Interface Software and Technology* (UIST '10), 333–342. DOI:https://doi.org/10.1145/1866029.1866080

[8] Danielle Bragg, Nicholas Huynh, and Richard E Ladner. 2016. A Personalizable Mobile Sound Detector App Design for Deaf and Hard-of-Hearing Users. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '16), 3–13. DOI:https://doi.org/10.1145/2982142.2982171

[9] Stacy M Branham and Shaun K. Kane. 2015. Collaborative Accessibility: How Blind and Sighted Companions Co-Create Accessible Home Spaces. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 2373–2382. DOI:https://doi.org/10.1145/2702123.2702511

[10] Stacy M Branham and Shaun K Kane. 2015. The Invisible Work of Accessibility: How Blind Employees Manage Accessibility in Mixed-Ability Workplaces. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (ASSETS '15), 163–171. DOI:https://doi.org/10.1145/2700648.2809864

[11] Charlotte Baker-Shenk and Dennis Cokely. 1980. Pidgin Sign English in the Deaf Community. In *American Sign Language.* Washington, D.C.: Clerc Books, 73.

[12] Kathy Charmaz. 2008. Constructionism and the Grounded Theory Method. In *Handbook of Constructionist Research.* 397–412.

[13] Kathy Charmaz. 2014. *Constructing Grounded Theory.* Sage Publications, London.

[14] Goedele A. M. De Clerck and Peter V. Paul (Eds.). 2016. *Sign Language, Sustainable Development, and Equal Opportunities: Envisioning the Future for Deaf Students.* Gallaudet University Press.

[15] Michael Crabb, Rhianne Jones, Mike Armstrong, and Chris J Hughes. 2015. Online News Videos: The UX of Subtitle Position. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (ASSETS '15), 215–222. DOI:https://doi.org/10.1145/2700648.2809866

[16] Starkey Duncan. 1972. Some signals and rules for taking speaking turns in conversations. *J. Pers. Soc. Psychol.* 23,

2 (1972), 283–292.
[17] Starkey Duncan. 1974. On the Structure of Speaker-Auditor Interaction during Speaking Turns. *Lang. Soc.* 3, 2 (1974), 161–180.
[18] Starkey Duncan and Donald W Fiske. 1977. *Face-to-Face Interaction: Research, Methods, and Theory*. Lawrence Erlbaum Associates, Hilldale, NJ.
[19] David A. Ebert and Paul S. Heckerling. 1995. Communication With Deaf Patients Knowledge, Beliefs, and Practices of Physicians. *JAMA* 273, 3 (1995), 227–229.
[20] Karen Emmorey, Robin Thompson, and Rachael Colvin. 2009. Eye Gaze During Comprehension of American Sign Language by Native and Beginning Signers. *J. Deaf Stud. Deaf Educ.* 14, 2 (2009), 237–243.
[21] Elisabeth Engberg-Pedersen. 2003. From Pointing to Reference and Predication: Pointing Signs, Eyegaze, and Head and Body Orientation in Danish Sign Language. In *Pointing: Where Language, Culture, and Cognition Meet*. Lawrence Erlbaum Associates, Mahwah, NJ, 269–292.
[22] Alexander Fiannaca, Ann Paradiso, Mira Shah, and Meredith Ringel Morris. 2017. AACrobat: Using Mobile Devices to Lower Communication Barriers and Provide Autonomy with Gaze-Based AAC. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing* (CSCW '17), 683–695. DOI:https://doi.org/10.1145/2998181.2998215
[23] Michele Friedner and Annelies Kusters. 2015. *It's a Small World: International Deaf Spaces and Encounters*. Gallaudet University Press.
[24] Gallaudet University. DeafSpace. Retrieved September 19, 2017 from http://www.gallaudet.edu/campus-design-and-planning/deafspace
[25] Ge Gao, Bin Xu, David C Hau, Zheng Yao, Dan Cosley, and Susan R Fussell. 2015. Two is Better Than One: Improving Multilingual Collaboration by Giving Two Machine Translation Outputs. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing* (CSCW '15), 852–863. DOI:https://doi.org/10.1145/2675133.2675197
[26] Ge Gao, Naomi Yamashita, Ari M J Hautasaari, and Susan R Fussell. 2015. Improving Multilingual Collaboration by Displaying How Non-native Speakers Use Automated Transcripts and Bilingual Dictionaries. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 3463–3472. DOI:https://doi.org/10.1145/2702123.2702498
[27] Carrie Lou Garberoglio, Stephanie Cawthon, and Mark Bond. 2016. *Deaf People and Employment in the United States: 2016*. Washington, DC. Retrieved from https://www.nationaldeafcenter.org/resource/deaf-people-and-employment-united-states-2016
[28] Darren Gergle, Robert E Kraut, and Susan R Fussell. 2004. Action As Language in a Shared Visual Space. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work* (CSCW '04), 487–496. DOI:https://doi.org/10.1145/1031607.1031687
[29] Abraham Glasser, Kesavan Kushalnagar, and Raja Kushalnagar. 2017. Deaf, Hard of Hearing, and Hearing Perspectives on Using Automatic Speech Recognition in Conversation. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '17), 427–432. DOI:https://doi.org/10.1145/3132525.3134781
[30] Charles Goodwin. 1981. *Conversational Organization: Interaction Between Speakers and Hearers*. Academic Press, New York.
[31] Charles Goodwin. 2000. Practices of Seeing Visual Analysis: An Ethnomethodological Approach. In *The Handbook of Visual Analysis*, Theo Van Leeuwen and Carey Jewitt (eds.). SAGE Publicaiton, London, 157–182.
[32] Charles Goodwin. 2000. Action and embodiment within situated human interaction. *J. Pragmat.* 32, 10 (2000), 1489–1522.
[33] Charles Goodwin. 2006. Human Sociality as Mutual Orientation in a Rich Interactive Environment: Multimodal Utterances and Pointing in Aphasia. In *Roots of Human Sociality*, Nicholas J Enfield and Stephen C Levinson (eds.). Berg, London, 96–125.
[34] Charles Goodwin. 2006. Interactive Footing. In *Reporting Talk: Reported Speech in Interaction*. Cambridge University Press, 16–46.
[35] Charles Goodwin. 2007. Environmentally Coupled Gestures. In *Gesture and the Dynamic Dimension of Language*, Susan D. Duncan, Justine Cassell and Elena T. Levy (eds.). John Benjamins Publishing Company, Amsterdam/Philadelpha, 195–212.
[36] Charles Goodwin and Marjorie Harness Goodwin. 1998. Seeing as a situated activity: Formulating planes. In *Cognition and Communication at Work*, Yrjö Engeström and David Middleton (eds.). Cambridge University Press, 61–95.
[37] Mara Green. 2015. One Language, or Maybe Two: Direct Communication, Understanding, and Informal Interpreting in International Deaf Encounters. In *It's a Small World: International Deaf Spaces and Encounters*, Michele Friedner and Annelies Kusters (eds.). Gallaudet University Press, 70–82.
[38] Jan Gugenheimer, Katrin Plaumann, Florian Schaub, Patrizia Di Campli San Vito, Saskia Duck, Melanie Rabus, and Enrico Rukzio. 2017. The Impact of Assistive Technology on Communication Quality Between Deaf and Hearing Individuals. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing* (CSCW '17), 669–682. DOI:https://doi.org/10.1145/2998181.2998203
[39] Marianne Gullberg and Kenneth Holmqvist. 2006. What speakers do and what addressees look at: Visual attention to gestures in human interaction live and on video. *Pragmat. Cogn.* 14, 1 (2006), 53–82.

[40] Steve Harrison and Paul Dourish. 1996. Re-place-ing Space: The Roles of Place and Space in Collaborative Systems. In *Proceedings of the 1996 ACM Conference on Computer Supported Cooperative Work* (CSCW '96), 67–76. DOI:https://doi.org/10.1145/240080.240193

[41] Christian Heath, Jon Hindmarsh, and Paul Luff. 2010. *Video in Qualitative Research*. Sage Publications.

[42] Christian Heath and Paul Luff. 1992. Collaboration and Control: Crisis Management and Multimedia technology in London Underground Line Control Rooms. *Comput. Support. Coop. Work* 1, 1 (1992), 69–94. DOI:https://doi.org/10.1007/BF00752451

[43] Christian Heath and Paul Luff. 1996. Convergent activities: collaborative work and multimedia technology in London Underground Line Control Rooms. In *Cognition and Communication at Work*, Yrjo Engeström and David Middleton (eds.). Cambridge University Press, Cambridge, 96–129.

[44] Christian Heath and Paul Luff. 2000. *Technology in Action*. Cambridge University Press.

[45] William C Hill, James D Hollan, Dave Wroblewski, and Tim McCandless. 1992. Edit Wear and Read Wear. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '92), 3–9. DOI:https://doi.org/10.1145/142750.142751

[46] Jon Hindmarsh and Christian Heath. 2000. Embodied reference: A study of deixis in workplace interaction. *J. Pragmat.* 32, 12 (2000), 1855–1878. DOI:https://doi.org/https://doi.org/10.1016/S0378-2166(99)00122-8

[47] James Hollan, Edwin Hutchins, and David Kirsh. 2000. Distributed Cognition: Toward a New Foundation for Human-computer Interaction Research. *ACM Trans. Comput. Interact.* 7, 2 (June 2000), 174–196. DOI:https://doi.org/10.1145/353485.353487

[48] Edwin Hutchins. 1995. How a Cockpit Remembers Its Speeds. *Cogn. Sci.* 19, 3 (1995), 265–288.

[49] Seray B Ibrahim, Asimina Vasalou, and Michael Clarke. 2018. Design Opportunities for AAC and Children with Severe Speech and Physical Impairments. In *Proceedings of the 36th Annual ACM Conference on Human Factors in Computing Systems* (CHI '18). DOI:https://doi.org/10.1145/3173574.3173801

[50] Lisa I. Iezzoni, Bonnie L. O'Day, Mary B. Killeen, and Heather Harker. 2004. Communicating about Health Care: Observations from Persons Who Are Deaf or Hard of Hearing. *Ann. Intern. Med.* 140, 5 (2004), 356–362.

[51] Hiroshi Ishii and Minoru Kobayashi. 1992. ClearBoard: A Seamless Medium for Shared Drawing and Conversation with Eye Contact. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '92), 525–532. DOI:https://doi.org/10.1145/142750.142977

[52] Hiroshi Ishii, Minoru Kobayashi, and Jonathan Grudin. 1992. Integration of Inter-personal Space and Shared Workspace: ClearBoard Design and Experiments. In *Proceedings of the 1992 ACM Conference on Computer-supported Cooperative Work* (CSCW '92), 33–42. DOI:https://doi.org/10.1145/143457.143459

[53] Dhruv Jain, Leah Findlater, Jamie Gilkeson, Benjamin Holland, Ramani Duraiswami, Dmitry Zotkin, Christian Vogler, and Jon E. Froehlich. 2015. Head-Mounted Display Visualizations to Support Sound Awareness for the Deaf and Hard of Hearing. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*. DOI:https://doi.org/10.1145/2702123.2702393

[54] Jennifer Johnson. 2012. *Rearticulating culture in a place in-between: Exploring the multimodal experiences of hearing mothers and their deaf children*. Retrieved from http://blc.berkeley.edu/2012/10/04/rearticulating_culture_in_a_place_in-between_exploring_the_multimodal_exper/

[55] Hernisa Kacorri, Matt Huenerfauth, Sarah Ebling, Kasmira Patel, and Mackenzie Willard. 2015. Demographic and Experiential Factors Influencing Acceptance of Sign Language Animation by Deaf Users. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (ASSETS '15), 147–154. DOI:https://doi.org/10.1145/2700648.2809860

[56] Sushant Kafle and Matt Huenerfauth. 2017. Evaluating the Usability of Automatically Generated Captions for People Who Are Deaf or Hard of Hearing. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '17), 165–174. DOI:https://doi.org/10.1145/3132525.3132542

[57] Shaun K. Kane, Meredith Ringel Morris, Ann Paradiso, and Jon Campbell. 2017. "At times avuncular and cantankerous, with the reflexes of a mongoose": Understanding Self-Expression through Augmentative and Alternative Communication Devices. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW '2016)*, 1166–1179.

[58] Shaun K Kane, Chandrika Jayant, Jacob O Wobbrock, and Richard E Ladner. 2009. Freedom to Roam: A Study of Mobile Device Adoption and Accessibility for People with Visual and Motor Disabilities. In *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '09), 115–122. DOI:https://doi.org/10.1145/1639642.1639663

[59] Saba Kawas, George Karalis, Tzu Wen, and Richard E Ladner. 2016. Improving Real-Time Captioning Experiences for Deaf and Hard of Hearing Students. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '16), 15–23. DOI:https://doi.org/10.1145/2982142.2982164

[60] Chris L Kleinke. 1986. Gaze and eye contact: a research review. *Psychol. Bull.* 100, 1 (1986), 78–100.

[61] Raja Kushalnagar, Poorna Kushalnagar, and Gianni Manganelli. 2012. Collaborative gaze cues for deaf students. (2012).

[62] Raja S Kushalnagar, Gary W Behm, Aaron W Kelstone, and Shareef Ali. 2015. Tracked Speech-To-Text Display: Enhancing Accessibility and Readability of Real-Time Speech-To-Text. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (ASSETS '15), 223–230. DOI:https://doi.org/10.1145/2700648.2809843

[63] Raja S Kushalnagar, Gary W Behm, Joseph S Stanislow, and Vasu Gupta. 2014. Enhancing Caption Accessibility Through Simultaneous Multimodal Information: Visual-tactile Captions. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility* (ASSETS '14), 185–192. DOI:https://doi.org/10.1145/2661334.2661381

[64] Raja S Kushalnagar, Walter S Lasecki, and Jeffrey P Bigham. 2014. Accessibility Evaluation of Classroom Captions. *ACM Trans. Access. Comput.* 5, 3 (January 2014), 7:1--7:24. DOI:https://doi.org/10.1145/2543578

[65] Paddy Ladd. 2003. *Understanding Deaf Culture: In Search of Deafhood*. Multilingual Matters, Bristol, UK.

[66] Walter Lasecki, Christopher Miller, Adam Sadilek, Andrew Abumoussa, Donato Borrello, Raja Kushalnagar, and Jeffrey Bigham. 2012. Real-time Captioning by Groups of Non-experts. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology* (UIST '12), 23–34. DOI:https://doi.org/10.1145/2380116.2380122

[67] Walter S Lasecki, Raja Kushalnagar, and Jeffrey P Bigham. 2014. Helping Students Keep Up with Real-time Captions by Pausing and Highlighting. In *Proceedings of the 11th Web for All Conference* (W4A '14), 39:1--39:8. DOI:https://doi.org/10.1145/2596695.2596701

[68] Kehuang Li, Zhengyu Zhou, and Chin-Hui Lee. 2016. Sign Transition Modeling and a Scalable Solution to Continuous Sign Language Recognition for Real-World Applications. *ACM Trans. Access. Comput.* 8, 2 (January 2016), 7:1--7:23. DOI:https://doi.org/10.1145/2850421

[69] Wendy E MacKay. 1999. Is Paper Safer? The Role of Paper Flight Strips in Air Traffic Control. *ACM Trans. Comput. Interact.* 6, 4 (December 1999), 311–340. DOI:https://doi.org/10.1145/331490.331491

[70] James R Mallory, Michael Stinson, Lisa Elliot, and Donna Easton. 2017. Personal Perspectives on Using Automatic Speech Recognition to Facilitate Communication Between Deaf Students and Hearing Customers. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '17), 419–421. DOI:https://doi.org/10.1145/3132525.3134779

[71] Helena M Mentis. 2017. Collocated Use of Imaging Systems in Coordinated Surgical Practice. *Proc. ACM Hum.-Comput. Interact.* 1, CSCW (December 2017), 78:1--78:17. DOI:https://doi.org/10.1145/3134713

[72] Helena M Mentis, Kenton O'Hara, Abigail Sellen, and Rikin Trivedi. 2012. Interaction Proxemics and Image Use in Neurosurgery. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '12), 927–936. DOI:https://doi.org/10.1145/2207676.2208536

[73] Helena M Mentis, Ahmed Rahim, and Pierre Theodore. 2016. Crafting the Image in Surgical Telemedicine. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (CSCW '16), 744–755. DOI:https://doi.org/10.1145/2818048.2819978

[74] Helena M Mentis and Alex S Taylor. 2013. Imaging the Body: Embodied Vision in Minimally Invasive Surgery. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13), 1479–1488. DOI:https://doi.org/10.1145/2470654.2466197

[75] Dorian Miller, James Culp, and David Stotts. 2006. Facetop Tablet:: Note-taking Assistance for Deaf Persons. In *Proceedings of the 8th International ACM SIGACCESS Conference on Computers and Accessibility* (Assets '06), 247–248. DOI:https://doi.org/10.1145/1168987.1169038

[76] National Center for Education Statistics. 2017. Disability Rates and Employment Status by Educational Attainment. Retrieved April 17, 2018 from https://nces.ed.gov/programs/coe/indicator_tad.asp

[77] National Center for Science and Engineering. 2017. *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2017*. Arlington, VA. Retrieved from www.nsf.gov/statistics/wmpd/

[78] Carol A Padden and Tom Humphries. 1990. *Deaf in America*. Harvard University Press.

[79] Carol Padden and Tom Humphries. 2009. *Inside Deaf Culture*. Harvard University Press.

[80] Anne Marie Piper and James D Hollan. 2008. Supporting Medical Conversations Between Deaf and Hearing Individuals with Tabletop Displays. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (CSCW '08), 147–156. DOI:https://doi.org/10.1145/1460563.1460587

[81] Anne Marie Piper and James D Hollan. 2009. Analyzing Multimodal Communication around a Shared Tabletop Display. In *ECSCW 2009*, Ina Wagner, Hilda Tellioğlu, Ellen Balka, Carla Simone and Luigina Ciolfi (eds.). Springer London, London, 283–302. DOI:https://doi.org/10.1007/978-1-84882-854-4_17

[82] Olof Sandgren, Richard Andersson, Joost van de Weijer, Kristina Hansson, and Birgitta Sahlén. 2014. Coordination of Gaze and Speech in Communication Between Children With Hearing Impairment and Normal-Hearing Peers. *J. Speech, Lang. Hear. Res.* 57, 3 (2014), 942–951. DOI:https://doi.org/10.1044/2013_JSLHR-L-12-0333

[83] Kristen Shinohara and Jacob O Wobbrock. 2011. In the Shadow of Misperception: Assistive Technology Use and Social Interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11), 705–714. DOI:https://doi.org/10.1145/1978942.1979044

[84] Brent N Shiver and Rosalee J Wolfe. 2015. Evaluating Alternatives for Better Deaf Accessibility to Selected Web-Based Multimedia. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (ASSETS '15), 231–238. DOI:https://doi.org/10.1145/2700648.2809857

[85] Liu Sicong, Zhou Zimu, Du Junzhao, Shangguan Longfei, Jun Han, and Xin Wang. 2017. UbiEar: Bringing Location-independent Sound Awareness to the Hard-of-hearing People with Smartphones. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 2 (June 2017), 17:1--17:21. DOI:https://doi.org/10.1145/3090082

[86] Patricia Siple. 1978. Visual Constraints for Sign Language Communication. *Sign Lang. Stud.* 19, 1 (1978), 95–110.

[87] Kiley Sobel, Alexander Fiannaca, Jon Campbell, Harish Kulkarni, Ann Paradiso, Ed Cutrell, and Meredith Ringel Morris. 2017. Exploring the Design Space of AAC Awareness Displays. In *Proceedings of the 2017 CHI Conference*

on Human Factors in Computing Systems (CHI '17), 2890–2903. DOI:https://doi.org/10.1145/3025453.3025610

[88] David Stotts, Jason McC. Smith, and Karl Gyllstrom. 2004. FaceSpace: Endo- and Exo-spatial Hypermedia in the Transparent Video Facetop. In *Proceedings of the Fifteenth ACM Conference on Hypertext and Hypermedia* (HYPERTEXT '04), 48–57. DOI:https://doi.org/10.1145/1012807.1012827

[89] Jürgen Streeck, Charles Goodwin, and Curtis LeBaron. 2011. Embodied Interaction in the Material World: An Introduction. In *Embodied Interaction: Language and Body in the Material World*. Cambridge University Press Cambridge, England, 1–26.

[90] Lucy A Suchman. 1987. *Plans and Situated Actions: The Problem of Human-Machine Communication*. Cambridge University Press.

[91] Dianne M Toe and Louise E Paatsch. 2010. The Communication Skills Used by Deaf Children and Their Hearing Peers in a Question-and-Answer Game Context. *J. Deaf Stud. Deaf Educ.* 15, 3 (2010), 228. DOI:https://doi.org/10.1093/deafed/enq006

[92] United States Department of Justice Civil Rights. Information and Technical Assistance on the Americans with Disabilities Act. Retrieved April 15, 2018 from www.ada.gov

[93] Clayton Valli and Ceil Lucas. 2000. *Linguistics of American Sign Language: An Introduction*. Gallaudet University Press.

[94] Belinda G. Vicars. Meeting and Interacting with Deaf people: "When and how to approach a Deaf person." Retrieved April 16, 2018 from http://www.lifeprint.com/asl101/topics/meeting-deaf-people.htm

[95] Ed.D. William Vicars. Attention Getting Techniques. Retrieved April 16, 2018 from http://www.lifeprint.com/asl101/topics/attention_getting_techniques.htm

[96] Ed.D. William Vicars. "Classifiers" American Sign Language (ASL). Retrieved April 16, 2018 from http://www.lifeprint.com/asl101/pages-signs/classifiers/classifiers-main.htm

[97] Michele A Williams, Caroline Galbraith, Shaun K Kane, and Amy Hurst. 2014. "Just Let the Cane Hit It": How the Blind and Sighted See Navigation Differently. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility* (ASSETS '14), 217–224. DOI:https://doi.org/10.1145/2661334.2661380

[98] Peter Wittenburg, Hennie Brugman, Albert Russel, Alex Klassmann, and Han Sloetjes. 2006. ELAN: a professional framework for multimodality research. In *5th International Conference on Language Resources and Evaluation (LREC 2006)*, 1556–1559.

[99] Yu-Han Xie, Miloň Potměšil, and Brenda Peters. 2014. Children Who Are Deaf or Hard of Hearing in Inclusive Educational Settings: A Literature Review on Interactions With Peers. *J. Deaf Stud. Deaf Educ.* 19, 4 (2014), 423–437. DOI:https://doi.org/10.1093/deafed/enu017

[100] Chien Wen Yuan, Benjamin V Hanrahan, Sooyeon Lee, Mary Beth Rosson, and John M Carroll. 2017. I Didn't Know That You Knew I Knew: Collaborative Shopping Practices Between People with Visual Impairment and People with Vision. *Proc. ACM Hum.-Comput. Interact.* 1, CSCW (December 2017), 1–18. DOI:https://doi.org/10.1145/3134753

[101] Annuska Zolyomi, Anne Spencer Ross, Arpita Bhattacharya, Lauren Milne, and Sean Munson. 2017. Value Sensitive Design for Neurodiverse Teams in Higher Education. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '17), 353–354. DOI:https://doi.org/10.1145/3132525.3134787

[102] Annuska Zolyomi, Anne Spencer Ross, Arpita Bhattacharya, Lauren Milne, and Sean Munson. 2018. Values, Identity, and Social Translucence: Neurodiverse Student Teams in Higher Education. In *Proceedings of the 36th Annual ACM Conference on Human Factors in Computing Systems* (CHI '18). DOI:https://doi.org/10.1145/3173574.31740737

[103] Sacha Zyto, David Karger, Mark Ackerman, and Sanjoy Mahajan. 2012. Successful classroom deployment of a social document annotation system. In *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems (CHI '12)*, 1883. DOI:https://doi.org/10.1145/2207676.2208326

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