Designing for Human-Machine Collaboration: Smart Hearing Aids as Wearable Technologies

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ABSTRACT

This study examines design aspects that shape human/machine collaboration between wearers of smart hearing aids and their networked aids. The Starkey Halo hearing aid and the TruLink iPhone app that facilitates real-time adjustments by the wearer offer a case study in designing for this sort of collaboration and for the wearer's rhetorical management of disability disclosure in social contexts. Through close textual analysis of the company's promotional materials for patient and professional audiences as well as interface analysis and autoethnography, I examine the ways that close integration between the wearer, onboard algorithms and hardware, and geolocative telemetry shape everyday interactions in multiple hearing situations. Reliance on ubiquitous, familiar hardware such as smart phones and intuitive interface design can drive patient comfort and adoption rates of these complex technologies that influence cognitive health, social connectedness, and crucial information access.

Categories and Subject Descriptors

H5.3.Group and organization interfaces: Computer-supported cooperative work

General Terms

Human Factors; Design

Keywords

Agency, deafness, disability, human/machine collaboration, interface design

Communication Design Quarterly.   ACM SIGDOC, New York, USA.

PRACTITIONER TAKE AWAYS

- Designing for human/machine collaboration can help medical wearables function as a portal to communication, social connectedness, information, and convenience.
- Designing to shift agency to the wearer for rhetorical management of disclosure is crucial for medical wearables.
- Interface familiarity and ubiquity can drive wearer adoption in medical contexts, particularly when medical wearables are a factor in disability disclosure.

INTRODUCTION

Let's begin with two everyday moments, each involving human-machine collaboration between a deaf body, a smart hearing aid, its algorithms, an iPhone, an app, data servers, and a satellite orbiting above all of them. At each turn, the actors in the network are interfacing, and some of them are functioning as interfaces.

I'm meeting a colleague from another department for a working lunch to discuss potential collaboration between our programs. As in all faculty dining rooms, ours contains a cacophony of voices that bounces off the walls and windows. While waiting for her, I appear to be fiddling with my smart phone, as nearly all of us do these days in such situations. But rather than check social media, I open the Tru-Link app that controls my smart hearing aid. After making sure that they both in fact connected via Bluetooth, I switch from the default setting to "Crowd," which enhances the directional mics and two intersecting algorithms that begin to classify input every six milliseconds and adapt to diminish noise between syllables every 20 milliseconds. Working with the BluWave OS that controls the aid, these actors discard noise behind my head and pull in voices directly in front of me before filtering out sounds identified as babble and clatter. Based on the number of voices in the room and the relative stuffiness of my sinuses, I also twiddle with the volume, adjusting it for the needs of the moment. As a hearing aid wearer of nearly four decades, I don't mind if anyone knows what I'm doing, but because of the ubiquity of the iPhone that I'm using, it's unlikely that anyone does. When my colleague arrives, I've made all the adjustments I need to make and we get right down to business. She's aware of my deafness because she knows me well, but she also likely assumes that I was checking Facebook when she came in. And since it's not relevant, I don't mention it. As she speaks, two compression algorithms work together to compress her higher pitched voice down to my lower hearing range.

Later, we pay the check and walk up the university hill into a cold February wind, bundled against the cold and damp. We're still hashing out some details as we head back to our buildings and it's a negotiation that depends on well-calibrated responses—and, thus, on accurately heard conversation. I'm walking on her right side so that my hearing aid is angled toward her. As we converse, the PureWave feedback eliminator identifies, classifies, and eliminates the feedback that my woolen hat is causing by being too close to the mics. The VoiceiQ algorithm minimizes the scratching sounds of the hat covering the aid's mics. As gusts of wind whip down the hill, it also throttles the wind noise, sorting her voice from the rush of air and then amplifying it according to pre-programmed settings that are calibrated for my hearing range. Thanks to this compounded filtration of the sound information that feeds into my ear canal, I'm able to devote my full concentration to the content of our conversation rather than the work of parsing what she's saying. I never have to pretend to understand or simply nod to stall while figuring out what has transpired. A few months from now, my audiologist will download the data that was recorded along the way and fine-tune the algorithms so that the nonhuman collective that is this hearing aid meshes even more closely with my physical hearing needs.

HUMAN/MACHINE COLLABORATION AND DISABILITY

The newest generations of digital hearing aids exemplify the ways smart interfaces are transforming the use of medical wearable technologies in everyday contexts. Older, stand-alone, analog aids simply amplified sound within the wearer's range and toggled to a telephone setting. Behind-the-ear models and larger in-the-ear models were primarily controlled with an onboard on/off switch and a rotating volume dial; using either required the wearer to understand how to operate them by touch rather than by sight since they were located behind the ear. [1] Now, the most contemporary models offer a combination of automated and wearer-driven functions that encourage an ever closer, more integrated relationship between the wearer and her devices. They also capture data and rely on a complex network of hardware, data servers, satellites, operating systems, and algorithms—along with variable involvement from a human wearer and audiologist.

In order to obtain maximum benefits from wearing a hearing aid, wearers must develop a skillset that involves both general skills and highly individualized listening processes. In real terms, one must learn to work closely with a machine that is inserted into a bodily orifice and whose consistent use affects cognitive processing and neural pathway development. Learning to be a successful wearer of any sort of hearing aid is a process, even for those of us who have worn aids for decades as I have. No hearing aid is plug and play; successful adoption requires learning to angle and manipulate an aid for maximum effect as well as close collaboration with a well-trained audiologist who can optimize fit and calibration. Over time, the aid becomes an integral part of the way you move through the social world.

Successfully working with a smart hearing aid requires even closer integration on the part of all the actors involved because there are a wider range of variables to successfully account for while negotiating complex environments and social cues: the technology, which includes hardware in the form of the hearing aid body, its nanocoating, and the ear mold as well as networked algorithms, a full OS, Bluetooth, data streaming, geolocation, and more. Not only the human learns in this situation; the aid also learns over time through basic machine learning processes. This collaborative learning process, which transpires over months and years, is partially driven by the human wearer but also partially driven by artificial intelligence and algorithms as data accretes, the hearing aid itself learns, and its settings are actively tweaked by humans so that they more closely align with the human wearer's hearing range and sound expectations. A number of models now on the market offer these capabilities, among them the Phonak Audeo, the Siemens Signia, and the Starkey Halo.

The autoethnographic case study offered in this article conveys several implications for communication design of multiple interfaces for medical wearables. My central focus is the design of interfaces and systems that facilitate human/machine collaboration in medical contexts. This report offers a close examination of the everyday collaborations that take place within a spatiotemporal collective of actors that include both humans and nonhumans, which Jack has explored in her own work on medical wearables (2016). Jack emphasizes the cultural implications of breast pump use by nursing mothers, driving home the ways that wearers must negotiate social expectations surrounding the conjunction of bodies and machines. My analysis joins hers by exploring the ways that human/nonhuman collaboration shapes the ways that hearing aid wearers negotiate communicative actions and interactive behaviors, particularly when accounting for working with automated agents in sound streaming, geolocation, and sound adjustment. By assuming that a collaborative and integrated relationship will develop between human and nonhuman, we can better design essential wearables as portals for social connectedness, information, convenience, and in the case of hearing aids, communication. Doing so requires moving beyond design processes that construct wearers and interfaces as separate agents with scheduled points of contact during early development and then not again until the usability testing stage.

Instead, starting with a conception of technological embodiment—one that offers an integrated vision of human and technology in which "technology, the body, and its actions become technologically embodied"—presents a more complex and useful vision from which to design (Meloncon 2013, p. 68). As Meloncon argues, "For the technical communicator, a malleable body that can be remade through technologies is more than a manifestation of cyborg, but rather the manifestation of a complex user, which can have wide ranging impacts on some of the most basic work of technical communication" (p. 68). This work extends across multiple communicative contexts as both disabled and abled-bodied users increasingly work collaboratively with smart machines—a use context that will only increase in coming years. The field's old divisions between human and nonhuman already no longer hold, Mara & Hawk write: "As organizations become more complex, technologies more pervasive, and rhetorical intent more diverse, it is no longer tenable to divide the world into human choice and technological or environmental determinism. Professional and technical communication is a field that is perfectly situated to address these concerns" (2010, p. 3). The implications are not limited to designs for disabled wearers; rather, considering technological embodiment as the default pushes designers to understand all wearers as technologically bodied and to design for the implications this presents for social use in public contexts.

A secondary thread in this essay focuses on designing for wearer agency in disability disclosure. Working with ubiquitous devices, building for close human/machine collaboration, and designing discrete, intuitive interfaces all contribute to designs that assist the wearer with deciding when and where she will disclose, assuming that contextual and bodily conditions also make this possible. If social conditions mean that disclosing disability affects safety, authority, and acceptance, good design offers the potential for human/machine collaboration that results in careful, rhetorical, collaborative management of disability within social situations. [2] Of course, if the conditions are right, disclosure and visibility are themselves important moves; the point is offering design that enables choice to the extent that it is possible. To offer a personal example: I do not identify as a member of the Deaf community, but neither do I consider deafness something to hide. I ask for accommodation as needed in conversations, in teaching, and in lectures and often fi nd myself publicly discussing the implications of being deaf in academia or of intersections between deafness and technology. But as any disabled person knows, encounters with ableist prejudices are inevitable. At those moments or in situations where there is other business at hand, it can be rhetorically strategic to render one's disability invisible as possible or to simply keep it out of the spotlight. [3] At times, I do so in order to preserve authority and favorable impressions of my competence, since misunderstanding speech is often confused with absence of the mental capacity to understand. When I discuss invisibility, it is within the context of rhetorical strategy rather than of shame.

For the d/Deaf, these strategies often arise from the basic need to earn a livelihood: [4] perceptions of d/Deaf people as less intelligent, less capable, or simply diffi cult to accommodate contributes to a 50% average unemployment for d/Deaf individuals in the United States. [5] The stakes are always high as we negotiate the appearance of deafness and the extent to which it is read by a society that privileges able bodies as the default. Safety is another impetus for hiding disability that is sometimes a basic daily psychological strategy and at other times, a vital necessity. Sometimes, safety involves avoiding bullying of the sort exemplifi ed by Donald Trump's 2016 Twitter exchange with Deaf actress Marlee Matlin, during which he implied that her deafness made her "retarded" (Suebsaeng & Resnick, 2016; Reilly, 2016). At times in recent history, the inability to appear to be "normal" hearing people has had far more dire consequences, as when the Nazi T-4 program isolated the disabled for forced sterilization, medical experimentation, and involuntary euthanasia. [6] At this particular moment in American history, though, many wearers' most pressing need is navigating daily social situations that are important for maintaining cognitive and mental health, employment, and social connections.

Smart hearing aids are at the forefront of meeting those needs. I focus my discussion on the original Starkey Halo model, which I have worn daily for the past three years, and the TruLink iPhone app 4.0 that controls it. The Halo offers an illustration of successes in intuitive design for a medical wearable as well as areas for improvement. This design enables some strategic operation: its' lack of onboard interface and reliance on an iPhone-based app with simple, modern interface design facilitates close collaboration between the wearer and the aid, affords rhetorical management of disclosure in conditions that allow it and rhetorically creates enhanced wearer perceptions of agency and control. However, several design assumptions and algorithmic realities result in breakdown, including assumptions about wearer identity that are evident in voice battery status notifications, automated Bluetooth streaming of sound notifications, and implications of geolocated SoundSpace Memories.

METHODS

In order to investigate the lived reality of this sort of long term human/machine relationship, this case study relies on autoethnographic methods that include systematic analysis of the network that comprises the Halo, close textual analysis of promotional materials that Starkey published for patient and practitioner audiences, interviews with my audiologist of nearly a decade, and analysis of the TruLink interface itself. I also present multiple narrative descriptions of individual use situations based on my own experiences. My background as a monaural wearer with four decades of experience with negotiating severe/profound deafness informs my decision to pursue an autoethnographic approach since it provides a way of connecting extensive lived experience with theory and research. Autoethnographic methods demand careful attention to "reflexively writing the self into and through the ethnographic text, isolating that space where memory, history, performance, and meaning intersect" (Denzin, 2014, p. 22). Far from being the simple presentation of stories, autoethnographies require considerable analysis and theoretical work and, by connecting with current conversations in the field, contribute to ongoing areas of scholarly inquiry. While this phenomenological approach is not generalizable, it offers important insight into successes and breakdowns in a long-term human/nonhuman collaboration in negotiating disability in social contexts.

This methodology is well-suited for professional communication, as Henry (2001) noted some time ago in his argument for it as a methodology that provides a perspective on technical communicators' relationships to cultural groups—in this case, to deaf wearers of hearing aids (2001, n.p.). Belinsky and Gogan also note its potential to "suggest practices that lead to more effective professional communication and document a need for a cultural change that results in increased professional equity or ethics," among other contributions (2016, p. 239). Autoethnographic methods have the potential to offer a close examination of detrimental discursive and cultural practices (Anderson 2006, Belinsky & Gogan 2016, Henry 2001 & 2013, Wilson & Ford 2003, Virtaluoto 2014) and to offer vital perspectives on issues related to gender, race, ableism, transnationalism, and a host of other hybrid identities (Adams, Jones, & Ellis 2015, Denzin 2014) that provide valuable information for design and ethical considerations.

Valuing rigorous reports of lived experiences also facilitates more fully rounded, more complex, and more ethical social science research of the sort that is frequently undertaken in user experience design. Ellis compellingly questions "how social science could leave out the particular, nuanced, and complex elements of social life. … If our task as researchers, as social scientists, is to study the social lives of humans, then we cannot relegate elements of human lives or experiences to the periphery, nor can we bracket out the ways that our lives and experiences are intertwined with our research project…" (Adams, Jones, & Ellis, 2015, pp. 8-9, emphases original.) Effective UX design must account for lived, social experiences outside of the usability lab as well as the important information we gain under lab conditions, enacting ethical design by valuing reporting that "democratize[s] the representational sphere of culture by locating the particular experiences of individuals in tension with dominant expressions of discursive power" (Neumann, 1996, p. 189). In the case of medical wearables, this ethical approach should be a foundational consideration since the technologies and interfaces often become deeply intertwined with the wearer's identity as well as their bodily and, in the case of hearing aids, cognitive experience of the world.

Accounting for the wearer's body requires accounting for the individual experiences of individual wearers, particularly those who use these technologies on a long-term basis. To do this, we must listen to these bodies speak about their experiences and the ways they move through the world alongside and in spite of their close relationships and collaborations with technologies. Careful inquiry into lived experience can never offer objective reporting, since no such thing is possible for beings who exist in relation to each other and communicate only in subjective terms. But what autoethnography can do—one way it can be be a vital source of critical information for technical communicators and UX designers—is offer lived perspective and careful interpretation of human relationships with technology. Through this methodology, I place the wearer's body and its hearing aid in both the predictable relationship of assistive technologies and the unpredictable relation of collaborators (Gannon, 2013), offering an exploration of the daily relationality of human-machine collaboration. "I am my body speaking," writes Pelias. "I am a mind/body fully engaged. I am a thinking and feeling agent trying to assemble some sense of it all, trying to let the cognitive and affective guide my way" (2013, p. 388). And in this article, I am a wearer communicating what I have made sense of thus far about this long-term experience of hybridity so that, among other things, designers have documented lived experience that may be incorporated into iterative design processes. In order to maintain this emphasis in the language of this piece, I refer to the humans in this study as wearers rather than users (unless they are audiologists), as "user" offers a disproportionate emphasis on human agency and de-emphasizes bodily participation. Following Liza Potts' assertion that "while referring to people as users is easy, doing so undermines the notion of how centrally important participation has become in systems" (2014, p. 8), my use of "wearer" emphasizes bodily engagement and active engagement in socially-focused choices.

The daily situations described in the introduction all take place in "hearing" contexts that are outside the Deaf community; all interactions are with interlocutors who either do not identify as d/Deaf or have not disclosed this identification. The narrative elements and central analysis in this article are offered from the perspective of individual embodied experience, and mine is that of someone who was born with normal hearing, became deaf post-lingually at nearly three years old, and received her education fully in mainstream environments. I do not sign and have always lived and worked in what are known as "hearing" environments, communicating exclusively through voiced conversation when I'm not writing, emailing, or texting. My needs and experiences are, therefore, different than those of someone who was born deaf or who experienced gradual hearing decline later in life and learned to accept and use an aid in, say, their 60s. They are also very different that those of someone who considers themselves part of the Deaf community and also part of the Deaf Pride movement, who communicates in sign language regularly. I do share the community's commitment to identifying instances of Deaf Gain, which focuses on benefi ts of deafness rather than constructing deafness as disability or Hearing Loss, [7] and argue that this article is one such example that offers an embodied perspective on mundane hybrid life and the implications of interface design.

SMART HEARING AIDS AS NONHUMAN COLLABORATORS

The Halo, introduced in March 2014, is controlled through an iPhone-based app rather than on-board buttons. This collective of agents affords the deaf wearer additional interaction with Bluetooth-based media streaming, satellite-based geolocation, and automated adjustment of sound settings based on detection of ambient noise. Throughout this discussion, I rely on Latourian descriptors of hybrid actors and collectives (Latour 1999, 2005). While I do not offer a full actor-network analysis, I use these terms because they offer a consistent framework that theorizes agency in ways that ascribe capabilities for influence and action to human, machine, and algorithmic agents alike. This framework also assumes by default that all actors are functioning within a spatiotemporal network, as the many moving human and nonhuman elements of the Halo and Tru-Link collective necessarily do.

Latour's famous example of a gun and a human functioning as separate actors that, when picked up, transform into the hybrid actor that is the gun-in-hand is particularly apropos. Together, the two actors are capable of actions that neither can perform separately. Beyond this new potential for performance, they are both transformed into a different, hybrid actor that exhibits its own agency (p. 178-183). [8] The same is true for the wearer of a hearing aid; the gun in the hand is the hearing aid in the ear. The aid is no longer an expensive piece of plastic in a box; the wearer is no longer a human isolated from verbal social interaction with all the implications that brings. In my own particular case, working closely with a hearing aid has altered the course of my life in terms of access to quality education, well-paid work, and a variety of social spheres. While wearing it, I participate in conversation, lead meetings, teach classes both large and small, collaborate on a range of projects, chat with my spouse, talk on the phone with my parents who live 1,200 miles away, and handle the small transactions of everyday life. Without it, I simply cannot participate in these situations in ways that are more than minimal. I could do all of these things to varying extents if I signed—and have brilliant colleagues around the country who do that very thing—but adding a sign language interpreter to the mix would bring attendant issues of negotiating bodies, perceptions, and authority [9] that relying on a hearing aid allows me to somewhat avoid. And the fact of the matter is that sign language is still not a lingua franca in modern American life; if a store clerk doesn't sign, it would not make much difference in that situation if I did.

When I teach doctoral seminars on the cultural implications of technologies, the topic of whether or not technology necessarily obscures essential elements of our humanity always comes up. I've taken to pulling out my hearing aid when this happens and passing it around the table on a tissue. As it goes around, I tell my students that without the aid or an interpreter, I cannot effectively function as their professor. I cannot converse with them, I certainly cannot lead discussion, and I cannot answer questions that they communicate to me verbally. Neither they nor I are fluent in sign language. I still know everything that I know and they of course know everything they know, but we can't have a conversation about it in ways that are typical of the admittedly ableist doctoral seminar format. I tell them that within my own lived experience, this little piece of plastic and wires is the difference between me stuffing envelopes in a subminimum wage sweatshop for the disabled or being their professor at a research university. [10] Then the hearing aid comes back around the room to me, I put it back in my ear, and we proceed with our discussion. Wearing the aid, as I do for around 16 hours each day, I become the public and professional version of myself, the one variously known as professor, colleague, friend, acquaintance, family member. As I negotiate conversational situations and auditory cues, every moment is mediated and every social interaction is experienced in collaboration with the distributed collective of agents that forms the Halo. They perform the technical work of hearing; I perform the cognitive work of listening. Together, we build my neural pathways and place in the world.

These intimately immersive qualities push the Halo into the foggy edge of wearables that are cyborgian. [11] An iPhone is certainly not a wearable, but the aid and its network are. "Wearable media sits midway between media you carry (e.g. laptops, Blackberrys, memory sticks) and media you become (e.g., devices implanted in the body, future nanotechnological manipulation, prostheses)," writes Isabel Pedersen (2013, p. 4). Hearing aids have long fallen under the medical defi nition of prosthetics, since they artifi cially replace a central bodily function. But hearing aids are fi rmly in the quadrant of media you become, given the ways that hearing is inextricably intertwined with cognitive health. Adults with untreated hearing loss experience a 30-40% decline compared to peers who maintain their hearing, and geriatric hearing loss is also clinically linked to depression driven by social isolation. Learning to work closely with a nonhuman actant that is worn deeply inserted in one's ear—transmitting information that one's brain reacts to in milliseconds in order to drive social responses—is a transformative act. The age at which one becomes deaf is crucial in the formation of language centers of the brain and in speech development. Children who become deaf postlingually, as I did, and are quickly fitted with assistive devices are more likely to succeed in mainstream educational environments (although learning in such environments still holds considerable challenges) and to develop speech that sounds "normal" to hearing audiences. [12]

The iPhone (or iPad or iPod or Apple Watch) [13] functions as a central and perhaps the most visible actor as the interface for wearer interaction and the nexus between most other actors, coordinating geolocation telemetry and automation as well as providing an interface for adjustments by the wearer. The patient brochure constructs an even closer integration with the Apple Watch, with which wearers can "control volume, change memories, and mute your hearing aids right from your wrist" rather than from a phone that is held and put down (Starkey, Halo, p. 6). This immersive physical proximity is a persuasive point throughout the brochure, which touts the fl exibility and mobility of Bluetooth streaming in similar ways: "Halo hearing aids provide direct streaming of phone calls, music, and media from your iPhone—so you can enjoy clear communication and pristine audio streaming anytime, anywhere, for an impressive, immersive sound." (Starkey 2015, p. 5, emphasis mine.)

Streaming is also interconnected with the iPhone's native automated agent, Siri, which the brochure notes can "read texts and emails directly to your Halo hearing aids" (Starkey 2015, p. 6). The construction of that claim is telling: Text is transformed into sound and Siri reads to the hearing aids, not to the wearer; an algorithm reads to a machine. In this formulation, the hearing aid and its wearer are a hybrid, actors working closely and transformatively together in order to receive, automatically transform, and then cognitively process information. Far from being overlooked, the wearer functions as the cognitive actor in this scenario, processing the information that has been relayed by algorithm to machine to algorithm to ear to mind. This promised human/machine integration is rhetorically positioned as a portal to communication, to social connectedness, to information, and to convenience. It is positioned as nothing less than a connection to the wearer's life, a life made better through hybridity: The cover of the brochure asks in large font, "Your world is at your convenience. Are you ready? If you're ready to laugh more, smile bigger, and connect conveniently to the things that make you happy, then you're ready to try Halo."

DESIGNING FOR HUMAN-MACHINE COLLABORATION

Encouraging hearing aid wearers to work closely with their devices rather than view them as a sort of one-switch solution to deafness is nothing new; user manuals from the 1940s and 50s also encouraged this sort of human-machine relationship. But the interfaces for older devices, with their on-board switches or hand-held remote, very much delineated human-controlled listening solutions. The Halo's capabilities, alongside the Tru-Link App, are designed to develop a much closer, integrated human/machine relationship that heavily incorporates automatic adjustments of personalized settings into the mix. Wearers also use the interface to engage with the aid in ways that were not possible in older versions of hearing aids and to make adjustments of their own. In this section, I detail the affordances as well as the necessary constraints of this collective, which permit the audiologist to purposefully bound the range of possible adjustments in order to limit potential harm. I also include discussion of ways that the Halo's design is rhetorically positioned in the promotional materials for patient and professional audiences.

The iPhone and its now-familiar iOS-based interface are at the heart of the Halo collective. The patient brochure foregrounds this intuitive design, informing the wearer right away that Halo "connects intuitively" to Apple devices so that you can "easily enjoy everything you do, anywhere you go" (Starkey 2015, p. 4). Feature descriptions begin with the most familiar: participating in phone conversations "with the touch of a finger." The activity of talking on the phone (rather than texting) is perhaps the most familiar to wearers in the over-50 target consumer demographic who may still view this as a primary use of their phones, and it is also an activity that has historically posed considerable problems for hearing aid wearers who have found that their aids produced feedback when placed against landline phone handsets or were incompatible with older models of cell phones that caused electromagnetic interference. Again and again, the brochure emphasizes familiarity and ease through physically interacting with the interface: The same page that described intuitive connectivity and phone calls also touts adjusting sound settings "by simply moving your finger on the screen" and "with the touch of your iPhone, you can easily" use your phone as a remote control, thus replacing the on-board switches or plastic remotes that controlled older hearing aids.

Implicit in this positioning are the facts that the novice wearer need not grapple with learning to operate buttons that they cannot see because they are located on or in their ear or with self-consciousness about repeatedly touching their ears in public or with using a conspicuous remote that is unfamiliar to others in social situations. The social stigma attached to hearing aids accounts for their low adoption rate: 20% among those with hearing loss in the 35-64 age bracket, 40% in the 65+ age demographic (Abrams & Kihm, 2015). The audiological design community has struggled with the perceived ugliness of hearing aids for more than 100 years, piloting such solutions as disguising aids as jewelry or cigarette cases in the mid-twentieth century and incorporating them into eyeglasses, a prosthetic that is far more culturally accepted. No solution aside from miniaturization has seen significant long-term adoption. Smart hearing aids like the Halo rhetorically negate this issue not by redesigning the hearing aid but by adding another device that is not just socially acceptable but also a status symbol. With the controls off-loaded, the behind-the-ear Halo is sufficiently small as to be hidden behind the ear lobe; its connective wire that runs between aid and ear mold is nearly invisible as it connects to a small, clear, in-canal mold. One can simply pull out a late-model iPhone, launch an app, and appear to be keeping pace with the times rather than publicly managing disability. This is a particularly important aspect for wearers who begin wearing aids due to geriatric hearing loss and who may feel self-conscious about the visibility of an aid.

Indeed, the Halo brochure for professionals relies on this factor in its projection of higher adoption rates: “Made for iPhone Halo will help reduce the stigma of hearing aids,” audiologists are assured, “and lead consumers to seek help sooner than they might otherwise” (Starkey 2013, p 9). The rhetorical positioning of the iPhone itself as familiar yet cutting edge technology, as an artifact that connotes both mobility and connectedness, and as a marker of middle-class status are all important, persuasive elements that invite closer collaboration from the human wearer. The professional brochure touts this familiarity more explicitly when it links the iPhone to patient satisfaction: “The iPhone is their phone, calendar, camera, contact list, entertainment center, communication hub and time killer all in one. It’s their indispensable connection to everything important to them” (8). This claim brings to mind Clark’s discussion of humans’ natural use of cognitive scaffolding such as calendars, notes, and the like as a natural extension and outsourcing of memory; smart phone functionality simply continues our natural tendencies to incorporate intuitive scaffolding into information processing and management (2003, Ch. 3 and p. 140). Why, then, should smart phones not also be an intuitive connection to hearing aids, devices that at first seem foreign as well as physically invasive when they are inserted into the ear? Introducing the iPhone as a way of interfacing with aids associates it not only with more direct patient control, but also with previous pleasurable experiences that are ingrained with phone use. The personal relationship that wearers establish with highly customizable phones is also an important factor: The Halo’s iPhone integration “transform[s] it from a high-performance hearing aid into the most personalized hearing solution ever” (11). Adding the iPhone as an interface shifts the hearing aid rhetorically as well as materially; it builds new persuasive appeals as well as affordances when it functions as, well, an interface for the interface that is the TruLink app.

Intuitive design and simplicity are also central factors in the success of the TruLink app interface, as with innumerable other user experiences currently on the market. The app invites interaction

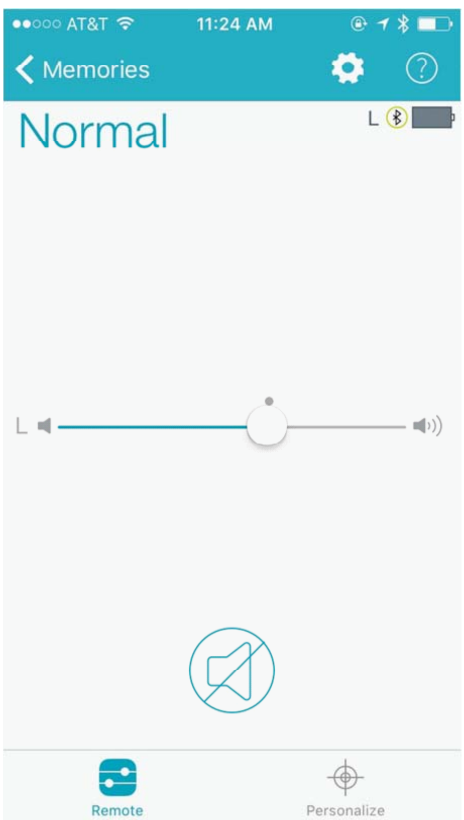

Figure 1: TruLink App home screen with volume control slider bar and setting name indication.

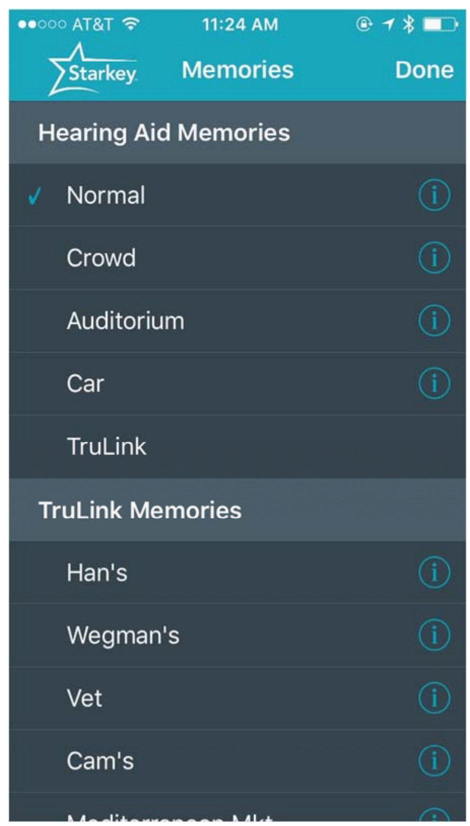

Figure 2: TruLink Memories Screens showing both audiologist-programmed and wearer-programmed custom settings.

through the simplicity of its design, which facilitates wearer adjustments by connecting wirelessly to the Halo's BluWave 3.0 OS. Figure 1 shows the home screen of the app, set to "Normal" setting and showing the volume control for my single hearing aid in my left ear.[14] The slider bar allows me to adjust the sound to be softer or louder, and the microphone icon with a slash through it mutes sound entirely. The battery icon in the upper right indicates that the aid's battery is new and fully charged. Clicking the gear icon at the upper right offers access to user manuals, help, and feedback options and well as the remote microphone/recorder option, the "fi nd my hearing aids" locator, and the demo mode. Should I need to toggle to a different setting, I press the word "Normal" to toggle to a second screen with multiple settings, seen in Figure 2. Here, I can select from settings that my audiologist and I collaboratively selected and calibrated for my hearing range: Crowd, which isolates speech and fi lters out room noise; Auditorium, which pulls in sound from further away; or Car, which fi lters out road noise when the iPhone's telemetry senses that I'm moving more than fi ve miles per hour. These algorithms have been transformative in both the way that I hear and the way that I collaborate with a hearing aid, since they do the work of noise fi ltering, separation, and amplifi cation far better than I can. Their functionality frees me to devote my cognitive efforts to parsing linguistic cues rather than trying to separate informative sound from noise that obscures it. On this screen, I can also select from several custom geo-tagged location settings if for some reason the aid hasn't automatically switched to them based on telemetry or I need to tweak them: the aforementioned grocery store, a couple of local restaurants, or our veterinarian's offi ce with its very odd acoustics. Much like the Crowd and Auditorium settings, these settings free me to engage in conversation without needing to devote as much cognitive space to filtering sound. If I need to set up a new memory, I return to the first screen and select the compass icon labeled "Personalize," which takes me to the SoundSpace settings screen (Figure 3). This interface relies on a Cartesian coordinate system that relies on spatial representation to facilitate personalized sound adjustments of making ambient noise louder or softer. The wearer can also adjust bass and treble in order to better account for human or animal communication, or for music. While making these adjustments, the human wearer works intimately with multiple algorithms, recursively adjusting and checking sound settings until the ambient sound is modulated for optimal human comprehension and engagement. These settings are saved as a geotagged memory that will be automatically accessed the next time the wearer is proximate to the location.

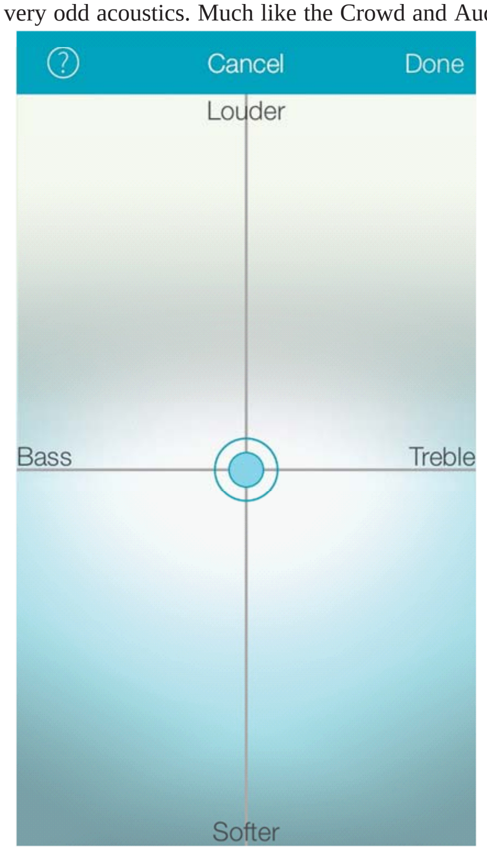

Figure 3: Cartesian coordinate system for custom adjustment of volume, bass, and treble within sound memories.

Individual location memories can also be further customized to decrease, mute, or turn off streaming from phone conversations while the aid is operating in a specific memory. The same changes can be made for audio streaming, and the car setting can be turned off entirely. These settings allow the human wearer to make fine-grained adjustments for environmental contexts—and, most importantly, to feel that they have individual, direct control over the collective that comprises their hearing aid. The phone interface also acts as a nonhuman proxy for the audiologist during daily listening situations, a fact that the professional brochure mentions in its direct address of audiologists: "The reality is, you can't be with your patients 24/7. TruLink and SoundSpace extend the relationship

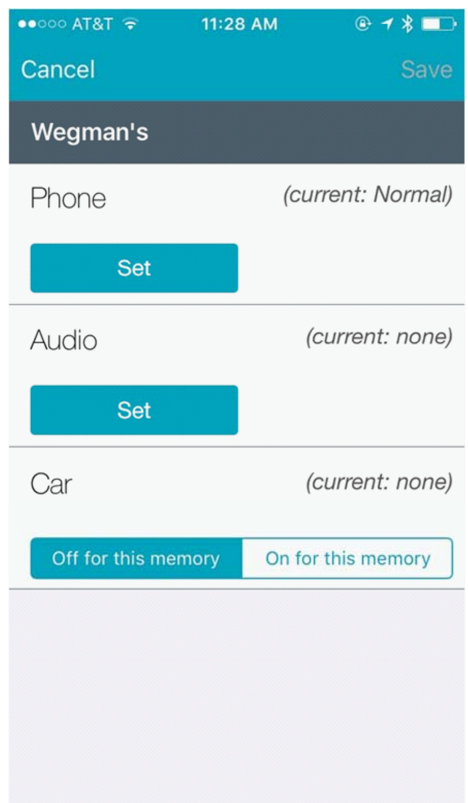

Figure 4: Custom adjustments within individual memory settings. The wearer can select phone ringer availability, audio settings, and whether or not telemetry for the car setting should be activated.

that you have with your patient by giving them a unique way to subjectively fine-tune sound—within reason… The results will be more patient engagement, faster acceptance, fewer follow-up visits, and increased satisfaction. Acceptance increases when patients have a say in how their hearing aids sound" (Starkey 2013, p. 13). Here, the aid is not just a proxy but a persuasive actor, convincing the human that life will be better lived with technology.

Recent updates to the app also include options for finer-grained control of ambient noise within location memories. Each of these screens allows the wearer even more direct interaction with the two InVision directional mics that are central hardware in each aid as well as the directional mic switching algorithm. The Machine Noise and Crowd screens facilitate further wearer access to the InVision Directionality mic system and the algorithms that work in concert with it that are collectively called Voice iQ. One algorithm classifies input every 6 milliseconds in order to distinguish voices from background babble, hums, or clatter and also adapts to diminish noise between spoken syllables every 20 milliseconds. The ISO compression and Spectral iQ frequency compression algorithms further adapt the sounds that have been identified as spoken language, applying custom compression settings in order to bring them into the wearer's hearing range. In my case, this means that I rely heavily on Spectral iQ to compress higher voices, birdsong, and the like into a lower range that I can perceive. By letting the machine do this for me, I'm able to engage more effectively with women who have stereotypically higher voices, detect high-pitched warning beeps, and experience the natural world more completely than I otherwise would.

AUTOMATED LISTENING

This automation is a central selling point in both the patient brochure and the professional information package for audiologists, but it is only described in the most general terms. Starkey never conveys to patients anything along the lines of "You'll have a robot in your ear!" but instead positions hearing aids as central to maintaining general physical and mental health before rhetorically aligning automation with efficiency and comfort. In fact, the term "automatically" always stands in for "automation," thus continuing claims for efficiency and simplicity. Adaptive Car Mode "automatically change[s] to a setting designed to reduce the annoying sounds of driving and enhance your 'audio' driving experience" (Starkey 2015, p. 5). The Auto Experience Manager, meant to help new wearers adjust to wearing aids, "automatically adjusts your … aid's loudness over time to help you transition to your new hearing experience in the most comfortable way" (ibid). The dual automation of Memories, which relies on both phone and aid, is positioned as convenience even when pervasive surveillance is mentioned. Memories are described as functioning this way: "a geotag memory uses the built-in GPS on your iPhone to know where you are, then automatically adjusts your Halo hearing aids to that tagged location" (ibid). Similarly, the prospective purchaser is informed that they can "easily find lost hearing aids using the Find My Hearing Aids feature, showing both a location and a timestamp" (ibid). These references represent the full discussion of automation in the patient brochure—for a hearing aid that includes at least seven algorithms.

However, the information for professional audiences does contain additional limited discussion concerning the intelligence of the Spectral iQ algorithm. This algorithm, which actively adapts as it identifies, selects, and compresses speech, is described as "a smart approach" and "the industry's smartest solution for high-frequency loss." A short description of functionality reports that "Spectral iQ's … enhance[s] real-time audibility by intelligently identifying high-frequency speech cues and replicating them in

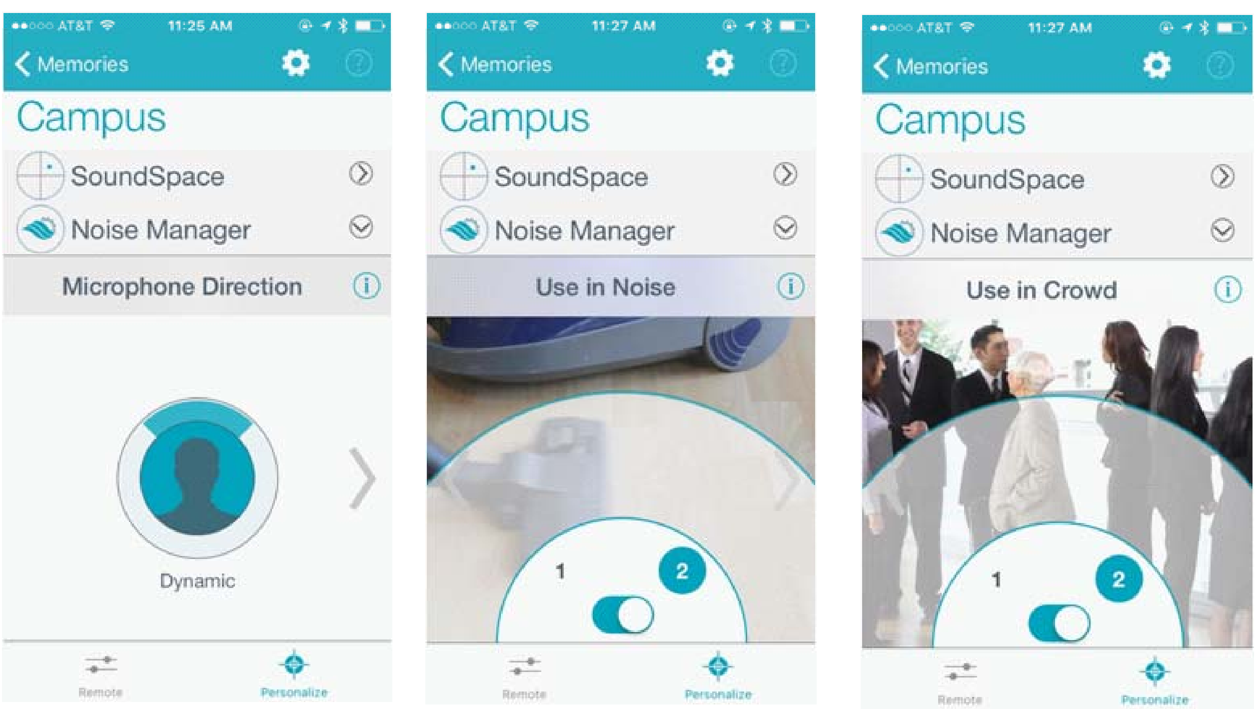

Figure 5: Custom noise management interfaces that facilitate limited wearer control of directional microphone switching, noise management, and filtration of babble, clatter, and ambient machine noises.

lower frequencies…" (Starkey 2013, p. 25). [15] In documents where the rhetorical task is to persuade both patient and professional audiences that they are each in control of this new technology, at least to varying degrees, automation can be intelligent, but it can never be an agent.

Disconnect and Breakdown

Not all aspects of human-machine collaboration function as smoothly as the Halo/TruLink elements I've discussed so far. Breakdowns and disconnects are an inevitable element of any interface and collective, and this one is no exception. Newer models of smart hearing aids include LifeLearning technology that renders the hearing aid a smart machine that actively learns use patterns and automatically recalibrates settings over time. This affords more nonhuman agency than in older models and allows the machine to function as more of a proxy for the audiologist, albeit one that is significantly less effective than a human who can account for unexpected vagaries and adjustments. Still, wearers who are reluctant to return to their audiologist for the multiple early visits that are necessary to tweak the settings of a new hearing aid are likely to benefit from algorithmic adjustments, which are better than none at all. For example, if the wearer consistently turns the hearing aid up rapidly, then the machine will learn to do it automatically. Sometimes this is beneficial because the wearer does, in fact, need more volume. But it is also possible to teach the aid bad behavior that leads to the machine constraining human hearing and thus the social interactions of the wearer. My own audiologist mentioned this, saying, "Sometimes people come in and say, you know, it's just not as loud as it used to be, things aren't working. I take a look and find that it's because LifeLearning learned from their trigger-happy button use and turned the hearing aid down" (M. Jordan, personal communication, March 9, 2017). As a result, she limits the adaptation range to 12 decibels, thus limiting the extent to which the machine can either dampen the wearer's social interaction or become so loud as to harm their residual hearing. This process accounts for the vagaries of recursive machine agency and flawed human behavior.

Wearer awareness of new automated features made available in updates poses another issue, particularly when automation is involved. On yet another day, I'm teaching in our computer lab, as I often do, stalking the tables full of students and computers, the hearing aid's Machine Noise setting busily filtering out all the clacking keyboards, beeping devices, rustling bags, and the rattling air ventilation of our old building. The directional switching pulls in a question from across the room, which I answer and then bounce to another student for perspective, and then we switch to production work. When I lean toward each team, their voices come into focus as the murmur of 17 other people is dulled based on proximity and angle, and we discuss the web site they are building and how it intersects with their client's parameters. All is working as it should, both in the class and in my hearing aid. A few minutes later, we've just returned to whole-group discussion about project management when my cell phone rings. It's an old-fashioned telephone bell ring set to the loudest setting, and it brings me to a complete halt. My students' lips are moving as they ask questions, but the ringing is all I can hear. Did I not remember to turn my phone off before class? I could swear I did, and I apologize to the students while running back to the lectern to switch the phone off. I do, and it still rings, and as I turn around I see that they're all looking at me as if I've gone slightly mad. It slowly dawns on me that they can't hear the rings, which, thanks to a new update, are now automatically streamed directly to my hearing aid via 2.4 GHz Bluetooth and not through the phone speaker that has indeed been manually switched off. The combination of automated streaming and incoming call completely interrupts my performance in the classroom, and the only way for me to stop the ringing is to reject the call or send it to voicemail. While waiting for the newly updated TruLink app to launch itself more slowly than usual, I curse the fact that I ran the update last night without checking on new features. And then I turn to explain the awkwardness caused by this interaction between human, machinery, and an audience.

Ostensibly, I could remedy this situation by setting up a SoundSpace Memory for the lab by using the interface in Figure 4 to indicate that I should never receive phone call notifications in this space. When I am in proximity to a location that has a memory set for it, the iPhone's satellite telemetry and native Maps app intersects with TruLink to prompt my hearing aid to automatically toggle to those settings. Problem solved. However, this assumes that satellite telemetry has sufficiently granular targeting to pinpoint locations that are close to each other rather than marking, say, an entire building as a Sound Memory. Unfortunately, the satellites that the phone relies on cannot currently pinpoint individual rooms within a building. The lab is located next door to my office, where I routinely need to receive calls for both business and personal reasons. If I set a memory for the lab, it will be processed as a memory for my office and indeed for the entire building that my department is located in. For similar reasons, I don't set a permanent "Auditorium" memory for the building directly behind ours where we hold all large functions, because the geolocation functions toggle into it both when I'm in the office and when I'm walking up the hill past the building, often in conversations that don't benefit from the sound suddenly including voices 20 feet away. The broader satellite targeting of this automated feature, driven by sophisticated machinery invisibly orbiting approximately 36,000 km above me, constrains me from using other automated features to remedy the problem of my phone ringing in my ear during class.

Later, I'm making a stop at the huge grocery store that I pass every day on the way to work. Its vast produce section has tile floors that cause cart wheels to rattle noisily across it. One busy Saturday, my husband used a noise meter app to measure the sound. It registered louder than most rock concerts; of course, that sound was amplified through the older hearing aid that I wore at the time, which did not have particularly fine-grained amplification or sound throttling. This store on a busy day is the only place I've ever had a panic attack other than the vast Minneapolis IKEA store. After getting the Halo, I used the Memories function to geotag the store and create custom sound settings that throttled the cart noise and sufficiently amplified voices. Lo, it worked, and thanks to working closely with algorithms I no longer experience physiological anxiety while buying lettuce. (This also has real benefits for my spouse, since shopping for groceries together is one of the happy weekly rituals in our household.) This is an obvious improvement, but because of the lack of precision in satellite telemetry, the settings toggled as I drove by the vast parking lot on the main street that is a good 300 yards from the building itself. Every day as I drove by on my way to campus, my experience of the music or conversation in my car shifted twice as the hearing aid switched into and out of the Wegmans memory. I updated the memory once the relevant updated was rolled out, but even now, if I've left the TruLink app on while driving, sound also shifts when I accelerate above 5 miles per hour as the phone telemetry activates Adaptive Car

Mode and tells the aid's algorithms to throttle road noise. Every stop light is a shift in and out of sound, presenting implications for holding conversations, for listening to music, and sometimes for maintaining train of thought.

Design assumptions about default wearer identity also drive communicative breakdown, since identity is a crucial element in what the wearer finds to connote comfort and a sense of safety. One of the most basic design elements for hearing aids is indicating to the wearer that the onboard batteries are about to run out. Older models simply quit functioning, while later models emitted a warning beep. The Halo offers a voice prompt, which one might suppose would be more personal and less confusing to novice wearers. But the default voice assumes that the wearer will be comfortable with a particular sort of voice directing them to change the batteries. At home one evening not long after first acquiring this hearing aid, I was alone in the house, prepping a chicken to go into the oven. Suddenly, a male voice said "battery" right in my ear. I jumped and the chicken landed on the floor with a splat. Having been unaware of this feature and having no sense of sound direction, it took me a few minutes to realize that my new aid speaks to inform me of its status. [16] The default voice is, of course, male with an American accent, a design choice that had sudden implications for my personal sense of safety on that particular evening. It was the first setting that I asked my audiologist to tweak in our follow-up visit, and now I have a British woman's voice to crisply demand "battery," the sound file for which my audiologist transmitted wirelessly to the aid in 45 seconds. While perhaps a slightly unusual choice for an American, it's not really that unusual for someone who grew up watching Mary Poppins and who still watches BBC series constantly. I chose it from accents and languages ranging from Welsh to Hmong. It tells me when 20 minutes are left and then when it is about to shut off, and I do as I am told lest I be left unable to hold voice conversations.

CONCLUSIONS

Smart hearing aids present complex use situations for wearers, audiologists, and designers of both systems and interfaces. The close human-machine integration required to be a successful wearer of these aids can lead to a collaborative relationship between human and machine as the wearer learns to work very closely with multiple machine agents that include hardware, directional mics, multiple processing algorithms, satellite telemetry, and an iPhone with an app that facilitates control of multiple functions as well as acts as a central element for geolocation telemetry. Over the course of my own deaf life, working closely with my hearing aids on a daily basis has meant that they have increasingly become part of who I am as a human, facilitating language and information acquisition, social interactions, cognitive health, extensive education, and gainful employment. Over the course of several decades, all of that adds up to who I am and who I am still in the process of becoming.

This case study offers implications not just for future versions of smart hearing aids, but for a wide variety of wearable interfaces that integrate closely with human bodies and especially with human cognitive processes. Designing for both disabled and able-bodied wearers who increasingly experience what Meloncon has termed technological embodiment means designing for human/machine integration. It means understanding medical wearables as not just life-enhancing or life-saving devices but as portals to communication that facilitate social connectedness, critical information processing, and in some cases, core alterations to physical or cognitive development. Given the potential for extraordinarily close human/machine collaboration in long-term wear situations that can stretch over decades, it's crucial to design for user experience that shifts agency to the wearer whenever possible when it comes to the rhetorical management of disability disclosure. Interface familiarity and ubiquity are central elements in disclosure management and in adoption rates. Designing for this sort of close human/machine integration should be a foundational concern in medical contexts, where wearers may not have a choice about whether or not they should wear devices on or in their physical bodies. This integrated existence is everyday existence, not a special set of circumstances, and design considerations can and should enhance wearables as portals for everyday life.

END NOTES

[1] The design I mention here was the most ubiquitous one during my lifetime of wearing aids (that is, post-1978). Older models that included a battery pack worn on the chest or in a holster on the arm or thigh also frequently placed volume dials on the packs. Some mid-century models disguised these packs and controls as cigarette cases. The earliest digital models relied on a remote control to be carried in the pocket as well as onboard buttons.

[2] For more on the ways these elements shape daily life as an academic, including issues related to authority in research and classroom authority, see Kerschbaum (2013) and Brueggemann & Kerschbaum (2015).

[3] This of course assumes significantbodilyprivilegethat affords the potential for keeping disability invisible as well as social contexts that afford this choice. In many circumstances, I can make this choice; in a busy restaurant at a table in the middle of the room, my choices are considerably reduced.

[4] Small-d 'deaf' is generally considered to refer to deaf or hard-of-hearing people who do not identify as part of the Deaf community; capital-D Deaf refers to those who do consider themselves part of that community, thus identifying as culturally Deaf in addition to physically deaf. Since the desire to hide deafness is understood as largely erased in the Deaf community through the Deaf Pride movement, I have used the generalized form throughout this document except where I explicitly refer to both communities.

[5] "Table 2.3: Civilians with Hearing Disabilities Ages 18 to 64 Years."

[6] For extensive discussion, see Brueggemann (2009).

[7] For more on this topic, see Baynton (2015).

[8] For more extensive theoretical discussion of rhetorical agency and human/machine collectives, see Kennedy (2016), pp. 31-35.

[9] See Brueggemann & Kerschbaum (2015).

[10] Subminimum wages for the disabled are a legal reality sanctioned by the Department of Labor. ("Subminimum wage.")

[11] For a popular narrative exploration of deafness and cyborg identity, albeit with cochlear implants, see Chorost (2005).

[12] Such speech development often still requires extensive speech therapy; I underwent five years of therapy between the ages of three and eight. This training and the use of assistive technologies is controversial within the Deaf community, since it largely erases Deaf language and communication while privileging ableist constructions of hearing and conversation. For more on this, see Weisberg & Aronson, 2000.

[13] The Halo is also compatible to varying extents with Android devices, but is only fully operational when controlled with Apple devices (Starkey, 2017).

[14] Dual hearing aid wearers would of course see a second control for their second hearing aid.

[15] For more on smart frequency compression, see Galster, Valentine, Dundas, & Fitz (2011).

[16] One can also check battery status within the TruLink app and, via Bluetooth, on the iPhone's native indication screen. Being a flawed human, I consistently ignore these indicators.

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