Function Augmented by Beauty: Assistive Medical Devices for Patient Empowerment

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Kayla Blalack

Spring 2024

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Advisor

Kent Wayland, Department of Engineering and Society

Introduction

What have we set as the visual language of medical devices? Why do so many convey weakness instead of healing, austerity instead of vibrancy, or artificiality instead of humanity? These opportunities are lost due to reliance on an age-old false dichotomy. The supposed contrast arises between aesthetics and functionality: a technology can either be state-of-the-art, highly functional—and ugly; or it can be beautiful yet simplistic. Medical devices, technologies that supplant and supplement bodily functions, are victims of this shortsightedness. The most susceptible category of these devices are ones that are noticeably worn by the patient. Therefore, the subset provides an appropriate starting point to dismantle the form vs. function debate. This investigation aims to answer, in part, the following question: *How can aesthetics add to the function of highly visible assistive medical devices?*

The ideal appearance of assistive devices continues to be debated by social groups beyond just patients. Instead of defining one perfect approach to medical device aesthetics, this research intends to facilitate the creation of wearable assistive devices that are readily embraced by users. This is accomplished by understanding aesthetics as a way to augment a device's function, not as a last-minute drain on engineering resources. Function for a medical device extends beyond mechanical motion or chemical reactions; it can also include patient compliance, improved mental health, and reduction of social stigma. For example, optimizing function with appearance will help patients feel comfortable, even empowered, when using a technology that addresses differences or deficiencies in their bodily function. Medical devices are built out of compassion for our fellow members of society. This compassion is most impactful when patients are provided with compelling and substantive solutions.

Background and Context

Highly visible assistive medical devices can primarily take the form of prosthetics (technology used to replace a part of the body), orthotics (technology used to support or enhance the body), or implants (embedded technology that supports bodily functions). All are frequently worn by the patient and are likely to be noticed by an outside observer, especially if the manufacturer has not taken appearance into account.

Over time, the devices have changed in response to design goals. Prosthetics have evolved with the primary goal of becoming more similar to their respective body parts in ability, with some focus on appearance. However, some prosthetics are now created to emphasize the difference in an engaging manner (Sansoni et. al, 2016). For example, prosthetic limb design can embrace a "cyborg" ideology or prosthetic eyes can display unnatural colors and patterns. Orthotics began as simple, hand-crafted machines, adjusted to mass-production, and are now experiencing a resurgence in custom design and aesthetic consideration due to advances in additive manufacturing (Barrios-Muriel et al., 2020). Implants utilize relatively new technology and have, in recent years, undergone efforts to reduce stigma and improve appearance. A good example is the insulin pump: some users of insulin pump implants keep them hidden, while others decorate them with stickers (Farrington, 2016).

Multiple social groups are affected by the creation and use of these assistive medical devices, most obviously injured and disabled people. The actions and opinions of these users are crucial. While less central to the story, medical device manufacturers, research labs, engineers, and designers benefit financially from the production of the devices and have significant influence on their design (as a researcher building an exoskeleton, I am part of the producers myself). The key distinction between users and producers is the relationship of each group with

the devices. Financial benefits may drive the creation of the technology, but they do not determine how it is used.

A patient's choice of when and how to wear a device is driven by function and response to societal stigma. Western society applies many negative connotations to disability, and outgroup members often conclude that a disabled individual is "lesser" than an able-bodied person (Darc Piculo dos Santos et al., 2020). The users of highly visible assistive medical devices are acutely exposed to these negative perceptions. Their devices are integrated with their bodies, affecting their own and others' perception of themselves. If a device leads to an individual being singled out, exposed to prejudice, or feeling self-conscious, it heightens disability stigma.

This stigma must be considered when weighing priorities for assistive medical devices. The users are often vulnerable members of society, exposed to prejudice on top of physical disadvantages. As J. E. Harris describes in "The Aesthetics of Disability," standing out can be harmful, as "collective tastes for normative representation of beauty, health, and effortlessness situate people with atypical sensory markers as risky" (Harris, 2019, p. 960). A maximally effective device should optimize the experience of the user with respect to this kind of stigma, whether by taking up as little visual weight as possible or by introducing aesthetically pleasing elements (Sansoni et. al, 2014; 2016). Device design balances what will be regularly and willingly used by patients with what will be ideal for their rehabilitation. If a device is visually unappealing, a patient may not use it as frequently as intended, which changes the desired treatment outcome (Darc Piculo dos Santos et al., 2020; Law et al., 2016). A technology with greatest effectiveness may not put the patient through medically ideal conditions in order to account for these social factors.

Literature

Researchers agree that a consideration of aesthetics can improve user satisfaction with assistive medical devices. Many authors recognize the benefits of aesthetically minded prosthetic limbs, while diverging on the ideal design focus. On one hand, Cairns et. al (2014) and Carroll & Fyfe (2004) argue that prosthetics that most accurately mimic the original limb are superior. They promote the idea of "cosmesis," the "preservation, restoration, or bestowing of bodily beauty," for improvement of amputees' mental health (cosmesis, n.d.). On the other hand, Sansoni et. al (2016) emphasize prosthetics that add some sort of visual appeal, whether natural or artificial. Overall, according to their earlier work, aesthetically attractive prostheses improve the emotional well-being of the user (Sansoni et. al, 2014).

Findings from additional, more varied, studies point to this increase in performance and user satisfaction. Law et. al (2016) noticed that user compliance increases with aesthetically pleasing scoliosis braces. Patients are more likely to use a device, from acapella® breathers, to epinephrine injectors, to scoliosis braces, if it looks and feels appealing to them (Lang et. al, 2013; Macadam et. al, 2012; Law et. al, 2016). Not only this, if the appearance of a device is neglected, such as with prosthetics, there can be negative psychological consequences (Luximon et. al, 2019). It is also relevant to note that aesthetics is one of the most common factors assessed by questionnaires evaluating the satisfaction of patients with orthotic devices (Bettoni et. al, 2016). This indicates a concern for aesthetics from designers and third parties, who acknowledge the impact it can have on users.

Literature also points to ways that considering aesthetics in medical device design gives the device additional features. As will be expanded on in future sections, orthotics can function as jewelry or other adornment (San Pedro Orozco et. al, 2019). The device then no longer serves

as a symbol of weakness—it becomes a positive accessory. Making assistive medical devices aesthetically pleasing can actively reduce social stigma for the user (Farrington, 2016; Harris, 2019; O'Kane et. al, 2015). The trading in of negative connotations for positive ones upgrades the technology to the uplifting position of advocacy, motivation, and empowerment.

Ultimately, Luximon et. al (2019) proposes, in the context of prosthetics, a bold assessment of the aesthetic contribution: assistive medical devices satisfy a basic function, or lowest level, on Maslow's hierarchy of human needs, but beautiful devices address the highest psychological well-being and self-fulfillment needs. Humans are elevated from living to thriving when supported beyond the minimum. The opportunity to control one's own presentation, as with considerations of visuals on medical wearables, is an excellent starting point for a patient to flourish.

Methods

The evidence needed to properly address the research question is devices in the category of wearable, highly visible assistive medical devices. Areas of interest include their usage by patients, regardless of the manufacturer's intentions, and the features contributing to their appearances when "worn" by patients. A snapshot of these was compiled by searching for relevant devices in manufacturer catalogs, online academic databases, and website sale pages. In addition, examples of alternative or expanded functions made possible by aesthetic considerations were found in scholarly literature on assistive medical devices. To avoid simply compiling another literature review on the impact of aesthetics, any source that identified a relevant device and its uses was considered, whether or not it commented on design intentions.

In order to collect evidence rigorously and systematically, a short list of devices was chosen to exhaust searches to a reasonable extent. These are: cochlear implants, hearing aids, orthotic braces, and diabetes management devices. They were chosen for being recognizable, but not so highly researched that an exhaustive search would be unreasonable (prosthetics fall into the latter category). The keywords used to find relevant sources were the name of the device plus "aesthetics," "appearance," or "cosmetic" in Google Scholar. To reduce confirmation bias, every relevant source was summarized regardless of contribution to perceived trends. This evidence was processed with bullet-point distillation of devices and their uses. It was then analyzed according to the lens of additional device functions gained by a consideration of aesthetics.

Results

The following cases explore three types of highly visible assistive medical devices and the ways that aesthetics are incorporated into their design. They identify commercially available devices and their aesthetic options, innovations made by device designers and researchers, and aftermarket adjustments and accessories created by the users themselves. The potential benefits of cosmetic considerations are highlighted as additional features of the device.

Among the devices, three clear new features emerged: serving as adornment and accessories, increasing feelings of agency, and combating negative perceptions of disability.

Case A: Hearing Aids and Cochlear Implants

Current market options for hearing aids and cochlear implants vary somewhat in form, but do not offer much in the way of aesthetic personalization. Hearing aids on the market come in four primary types, each presenting its own tradeoff between visibility, obtrusiveness to the inner ear, and ease of use (Everett, 2023). These are shown in Figure 1. In general, upscale hearing aids can be found in a small range of metallic and neutral colors (GN Consumer Hearing Corporation, 2024; hearX Group, 2024). However, some models, especially lower-cost options, are only available in a single silver or light tan color (Lucid Hearing, 2024; Audien Hearing, 2024). The slim range of color options is shown in Figure 2. When it comes to cochlear implants, Cochlear, one of the most dominant manufacturers, produces three different designs in varying sizes and colors. The least obtrusive of these is the Baha, or bone-anchored hearing aid. However, the products all vary in function and features, which are likely to be the primary influence on a patient's choice (Cochlear, 2024) There is little to no customization available to the patient after they have made a selection based on functionality. Some manufacturers advertise their cochlear implants as "bionic ears" (Campbell, 2005, p. 2). This positive reframing of the implant's function could act as a palliative for internalized disability stigma, but it does not address the impression of a person upon seeing the device in use.

Instead, the adjustment of the device's impression has been taken on by some proactive makers. With some savvy enhancement, the placement and visibility of a hearing aid lends itself well to usage as an accessory or adornment. One example of this are the custom ear molds created by Mike Sonnenberg in Figure 3, which elevate hearing aids from clinical to fashionable.

Figure 1

Four Primary Styles of Hearing Aids (Everett, 2023)

Figure 2

The Color Range for Lexie Lumen (hearX Group, 2024) versus Atom (Audien Hearing, 2024) Hearing Aids

Figure 3

Custom Ear Molds by Mike Sonnenberg (2017a; 2017b)

Another instance of accessorizing comes from proactive users in Profita et. al (2016; 2018), which describes the inner workings of a Facebook forum of hearing aid and cochlear implant customizers. These users decorate their assistive devices using do-it-yourself materials such as nail polish, stickers, and tape in order to add to self-expression and personalization of the devices. Not only does the improved appearance reduce a visual blight, it causes the wearer to feel more in control of their image. On the consumer end, acting to improve aesthetics with cochlear implants and hearing aids brings a sense of agency.

During the device design phase, there is still room for attention to self-expression, however. Studies and interviews with the aim of engaging patients in the design of their own devices reveal additional benefits of aesthetic consideration in early stages. Wilde & Marti (2018) conducted a workshop with deaf women, jewelry makers, and engineers to design

alternative devices for hearing assistance with a novel aesthetic focus. The workshop was rooted in co-design, which helped the deaf women feel in control of their bodies and technologies. It also reframed disability to reduce social stigma: by focusing on the fashion, expression, and augmentation potential of wearable hearing aids, the devices are not simply a solution for a deficiency. When Ellington & Lim (2013) interviewed teenagers about their ideal hearing aids, some adolescent girls imagined them to look like earrings. A hearing-aid earring adds an accessory dimension to the device, making it fashionable and cool. In particular, one female participant who was interested in fashion design drew plans for a light-up earring-style hearing aid with mirrored elements. Her re-envisioned hearing aid has the potential to feed her creativity and desire to accessorize her outfits. Other adolescent girls, meanwhile, reported hiding their cochlear implants with hair or other disguises (Hilton et al., 2013; Ellington & Lim, 2013). A different device design with unobtrusiveness in mind might fulfill the additional function of eliminating the visual impact, not just the functional/behavioral effects, of a hearing disability. Whether maximizing a positive visual impact or minimizing a negative one, devices designed with these appearances in mind would be more useful than the status quo.

Whether undertaken by the device's manufacturer or user, attempts to improve the appearance of cochlear implants and hearing aids lead to new dimensions of the device's function. These include critical self-expression to gain control over a disability, accessorizing for visual appeal, and the potential elimination of the effects visually, not just functionally or behaviorally. One theme of note across examples of aesthetic customization is the involvement of the user—no matter the side of the design process, user input is essential to maximize the aesthetics of a device.

Case B: Orthotic Braces

Orthotic braces are widely produced across the medical device industry. Orthotic companies today offer a small variety of colors within design styles that seem similarly sporty, especially within the category of fabric braces (Bauerfeind, 2024; Orliman, 2024, BSN medical Inc., 2015). They are also notable for the wide variety of materials and manufacturing methods that can be used in a successful product. As opposed to the highly technical cochlear implants and insulin pumps, many functional examples are even homemade. This accessibility leads to a wealth of academic and aftermarket innovations.

First, the added feature of accessorizing with appearance-minded orthotics is exemplified by braces specifically created to look like pieces of jewelry. San Pedro Orozco et. al (2019), Bush & ten Hompel (2017), Park & Cho (2011), and McKee & Rivard (2011) have designed metallic braces for fingers, wrists, ankles, and knuckles. As with hearing aids and cochlear implants, the idea of a highly-visible assistive medical device fulfilling the additional function of an adornment is novel and appealing. Bush and ten Hompel (2017) refer to this as "therapeutic jewellery," which "functions as a crafted object to offer dignity and grace to people's lives," (p. 101). Heightened dignity comes in part from an increase in communication for the patient, as noted by Park & Cho (2011). The option of a beautiful orthotic brace gives the user more agency, and therefore a stronger sense of connection with the device itself. It also increases the amount of control the user has over their self-presentation. They can better communicate their aesthetic preferences with an emphasized orthotic as jewelry.

One new innovation is a divorce from the ubiquitous flesh-toned orthotic. González et al., (2012) endeavor to understand users' needs regarding fabric orthotics, among other devices used by disabled people. They suggest that patients should get to choose the colors and patterns on

orthotics, as common peaches and tans are not appealing. In this vein, when Law et. al (2016) interviewed adolescent scoliosis patients about their ideal back brace, the aesthetic elements mentioned were custom colors, graphics, and embellishments. The contrast between the traditional scoliosis brace and newer designs, like the James Dyson Award-winning Airy brace, is visible in Figure 4. The adolescents' desire for change stems in part from disability stigma. Multiple patients mentioned disliking flesh-tone braces because they are "the same color as a prosthesis which disabled people use," (Law et. al, 2016, p. 879). This comment is particularly noteworthy because it simultaneously disdains disabled people and denies the patient's own relationship to disability. If stigma is so ubiquitous as to arise both internally and externally, any lessening of negative associations is a crucial benefit. Additional benefits of steering away from standard brace designs are supported by Lahoud et. al (2020), whose research on ankle braces indicates that added graphics make them desirable to children: a Superman design imbues a young girl with super speed, and a butterfly pattern gives another an accessory to show off. The more desirable, the better; regular usage of braces is crucial for treatment outcomes.

Figure 4

Standard Scoliosis Brace (ScoliosisPTJax, 2020) vs. the Airy Scoliosis Brace (Englefield, 2022)

When it comes to agency, innovations in additive manufacturing methods have made it easier to create nontraditional-looking orthotics according to users' desires. A prototype 3D-printed orthosis took advantage of the manufacturing method to add an appealing "Voronoi pattern"—a geometry that creates cell-like links to maximize strength while minimizing material used (Agudelo-Ardila et al., 2018, p. 4). This accomplishes two features at once: it makes the brace a more efficient use of material while increasing its cosmetic interest. Meanwhile, a 3D-printed orthotic design developed by Portnova et al. (2018) touts its versatility in aesthetic options via choices of component and strap colors. 3D printing is fast and cheap enough that it allows for increased flexibility. The designers' results after surveying patients also indicated the variability in tastes from person to person, as the category of "aesthetics" had the largest spread in participant rankings. User satisfaction with aesthetics can be maximized and added onto existing satisfaction with device performance, especially given advances in manufacturing that allow for quick and easy customization.

While many adjustments to orthotic braces in service of cosmetic appeal have led to designs that positively highlight the device, there are also aesthetically minded devices that minimize its appearance. In response to performance issues with traditional rigid-frame scoliosis braces, Matthews & Wynne (2021) designed a brace using elastomeric fabric. The result was an athleisure-style bodysuit that is significantly more discreet and, the authors assert, ensures much more regular use by patients. Different patients are differently susceptible to self-consciousness when wearing an orthotic device. Aesthetic consideration in the design process can account both for people who want to show off and who want to keep devices hidden. Once again, patient agency is increased and disability stigma is diminished.

Design researchers and patients, working together, have created orthotic braces that improve on the aesthetics of mass-market devices. Whether adding colors and patterns, turning braces into jewelry, or customizing structures and textures with additive manufacturing, this additional attention augments the brace's functionality. New approaches to braces do not just support body parts—they lessen stigma, offer adornment, and increase satisfaction.

Case C: Diabetes Management Devices

Contemporary diabetes management requires two primary devices: an insulin pump and a glucose monitor. Insulin pumps allow for automatic insulin dosing, rather than the more traditional self-monitoring of blood sugar levels and administration of injections. Glucose monitors are sold either as small meters, which read a drop of the patient's blood on a test strip, or a small continuously monitoring white sticker on the body (Abbot, 2019). Pumps are sold either as devices about the size of a cell phone with a tube that connects into the body or as more discreet patches on the abdomen (Medtronic, 2013; Bowen & Allender, 2016). Patch pumps, as argued by Laubner et al. (2019) increase flexibility and compliance due to the absence of tubes. Even newer devices combine glucose monitors and pumps (Lal & Leelarathna, 2023). Many users still use the two separately, however, as shown in Figure 5. Scheiner (2012) identifies the visual consumer choices as "color options, clip/case quality, physical dimensions, tubing versus tubeless (patch), and general appearance," (p. 129).

Figure 5

Insulin Pump and Continuous Glucose Monitor (Medtronic, 2013)

Design of these devices sometimes intends to mimic other non-medical technology. Hazelton et al. (2019) classifies this idea as an enhancement of the aesthetic appearance. Discreet design, they argue, whether by hiding or disguising an insulin pump, can make it look "less 'medical' and more beautiful" (p. 177). Some producers have attempted to meet this challenge, such as a company that designed a combination glucose monitor and insulin pump that looked like a USB stick (Brookes, 2010). Rentschler & Nothwehr (2021) examine insulin pens and pumps on the market as devices that replace a syringe's medical connotations with more positive ones of writing implements and mobile phones. Other designs mimic pagers, mp3 players, and

iPhones. Overall, intentionally adjusting the appearance of devices to look less medical removes many of the negative connotations for patients and observers. It can even spark a change in public mentality from diabetics being sick to being people living full lives (Brookes, 2010).

Beyond major manufacturers, engineers are rethinking the design of diabetes technology. From a contact lens sensor to color-changing tattoo ink, there are now many innovations for monitoring glucose levels (Elsherif et al., 2022; Yetisen et al., 2019). These innovations prioritize form and function. The contact lenses allow patients to discreetly manage their condition with the choice of when to reveal it to others. Tattoo ink, besides decorating a patient's body, could enhance it with futuristic features that make it arguably more interesting than a fully abled body. On the insulin pump side, Faraji & Kasiri (2013) designed a new system for Iranians with aesthetics in mind. They added a range of metallic colors for adults, bright colors for children, soft edges, and visual cohesiveness between the pump and monitor. With all of these new designs, users can gain a "sense of distinction and uniqueness…rather than inducing illness as a medical device" (p. 126). The visual coordination could be especially beneficial compared to the standard. Pumps and glucose monitors are not guaranteed to look good together. Attention to cohesiveness across devices that are used multiple times a day could replace feelings of clutter with an appreciation of beauty.

Consumer adjustments to their diabetes devices draw attention to them by making them intentionally decorative. While Ritholz et al. found in 2007 that highly visible insulin pumps prompted "feelings of being different and less acceptable," (p. 553), in a more recent thesis work Peterson (2023) concludes that increased visibility of diabetes management devices allows diabetic users to identify themselves to others. Since diabetes is otherwise invisible, this can strengthen relationships between diabetics to form a positive community. It could also draw

neutral or positive attention to the condition to make it seem more normal, reducing the "othering" that many medical conditions receive. This may be, in part, why there are now a wide variety of pump and glucose monitor embellishments sold by third-party companies. Multiple commercial businesses sell bright-colored and patterned stickers for nearly every available device, shown in Figure 6 (Pump Peelz, 2024; Type One Style, 2024; Pimp My Diabetes, 2024). Pals et al. (2021) and Farrington (2016) noticed this as a phenomenon among users of all ages. They see device decorations as a way of challenging negative perceptions. Making a device more noticeable, as long as it is visually appealing, can connect patients to others and work towards eliminating stigma.

Diabetes management devices are unique in that they can be a collection of individual tools or one closed-loop system. Despite this variety, many designs mimic non-medical technology to avoid associations with illness. They can make the condition more discreet, or more visible, depending on the user's preference. Overall, aesthetic consideration works to reduce or challenge stigma that is present for diabetics managing an otherwise invisible disease.

Figure 6

Decorative Stickers for Glucose Monitors (Pump Peelz, 2024; Type One Style, 2024; Pimp My Diabetes, 2024)

Conclusion

The importance of considering aesthetics at the expense of functionality when creating technology is commonly up for debate. When the question is applied to medical devices, technology meets stigmas, slim margins of error, and subjective ideals of beauty as form and function overlap. The form vs. function debate is a false dichotomy. Of course, devices must not sacrifice base features for visuals, but they cannot ignore them either. It is incredibly important for medical devices to work well, but the definition of working well is more than just enabling bodily function. Rather than take a side in the debate, the benefits of form are taken as something that can be *added* to traditional device functions.

Research on relevant devices reveals gaps in the current feature sets of highly visible assistive medical devices: there is a need for functionality beyond the physical. For one, a device's presence can change the user's exposure to internal and external stigma, which is not commonly addressed. Moreover, if the appearance of the device is not taken into account, there can be severe psychological consequences. Beyond just eliminating a negative, it is also clear that considering aesthetics in the design process can be beneficial; research has shown that visually appealing medical devices increase psychological well-being and alleviate stigma. These benefits should be maximized.

An investigation of three primary categories of highly visible assistive medical devices revealed several ways that visual considerations can add to the functions of the device. Across hearing aids, cochlear implants, orthotic braces, insulin pumps, and glucose monitors, attempts to make technology more beautiful adds to a device's list of functions. Devices can serve as adornment and accessories. They can increase feelings of agency in populations vulnerable to low self-esteem. They are more usable on a regular basis, which leads to better treatment results.

Perhaps most importantly, better design for devices actively fights negative perceptions of disability. The result is a technology that causes its user to feel more empowered in their own body.

Future research is needed to explore the ways that in-depth aesthetic considerations can be most naturally incorporated into the standard technology design process. Ideally, future medical devices will feel appealing and personal right out of the box, without the need for significant modifications. One emergent theme from the communities of aftermarket adjusters, design researchers, and small businesses was the benefit of co-designing with patients. A device's functionality comes from the decisions made by its designers. In order to best augment function with beauty, users should contribute from the start.

References

Abbott. (2019). *FreeStyle Libre Continuous Glucose Monitoring*. FreeStyle Libre US. https://www.freestyle.abbott/us-en/home.html

Agudelo-Ardila, C. P., Prada-Botía, G. C., & Rodrigues G, P. H. (2018). Orthotic prototype for upper limb printed in 3D: A efficient solution. *Journal of Physics: Conference Series*, *1388*, 012016. IOPscience. https://doi.org/10.1088/1742-6596/1388/1/012016

Audien Hearing. (2024). *Audien Atom Series*. Audienhearing.com. https://audienhearing.com/

Barrios-Muriel, J., Romero-Sánchez, F., Alonso-Sánchez, F. J., & Rodríguez Salgado, D. (2020). Advances in Orthotic and Prosthetic Manufacturing: A Technology Review. *Materials*, *13*(2), 295. MDPI. https://doi.org/10.3390/ma13020295

Bauerfeind. (2024). *Braces & supports: knee, back, ankle, shoulder injuries*. Bauerfeind. https://www.bauerfeind.com/b2c/

Beckenstein, M. S., Steenerson, R. L., Elliott, L. F., & Hartrampf, C. R. (1999). Use of a Superficial Temporal Fascia Flap for Coverage of an Exposed Cochlear Implant. *Otolaryngology-Head and Neck Surgery*, *120*(6), 940–942. https://doi.org/10.1016/s0194-5998(99)70343-8

Bettoni, E., Ferriero, G., Bakhsh, H., Bravini, E., Massazza, F. & Franchignoni, F. (2016). A systematic review of questionnaires to assess patient satisfaction with limb orthoses. *Prosthetics and Orthotics International*, 40(2), 158-169. https://journals.sagepub.com/doi/full/10.1177/0309364614556836

Bowen, J. L., & Allender, C. J. (2016). A Comparative Pulse Accuracy Study of Two Commercially Available Patch Insulin Infusion Pumps. *European Endocrinology*, *12*(2), 79. Pub Med Central. https://doi.org/10.17925/ee.2016.12.02.79

Brookes, L. (2010, April 7). *Why Can't a Diabetes Device Be as Cool as an iPod?* Medscape. https://www.medscape.com/viewarticle/719699?form=fpf

BSN medical Inc. (2015). *BSN medical Orthopedics Catalog*. BSN medical Inc. https://medical.essityusa.com/fileadmin/z-countries/0-USA_NEW/PDF_FILES/61861_RN_Orthopedics_Catalog.pdf

Bush, P., & ten Hompel, S. (2017). An integrated craft and design approach for wearable orthoses. *Design for Health*, *1*(1), 86–104. Taylor & Francis Online. https://doi.org/10.1080/24735132.2017.1299439

Cairns, N., Murray, K., Corney, J., & McFayden, A. (2014). Satisfaction with cosmesis and priorities for cosmesis design reported by lower limb amputees in the United Kingdom: Instrument development and results. *Prosthetics and Orthotics International,* 38(6), https://journals.sagepub.com/doi/full/10.1177/0309364613512149

Campbell, F. K. (2005). Selling the Cochlear Implant. *Disability Studies Quarterly*, *25*(3). https://doi.org/10.18061/dsq.v25i3.588

Carroll, Á. M., & Fyfe, N. (2004). A Comparison of the Effect of the Aesthetics of Digital Cosmetic Prostheses on Body Image and WellBeing. *JPO: Journal of Prosthetics and Orthotics*, *16*(2). https://journals.lww.com/jpojournal/fulltext/2004/04000/a_comparison_of_the_effect_of_the_aesthetics_of.7.aspx

Cochlear. (2024). *Products and candidacy*. Cochlear. https://www.cochlear.com/us/en/professionals/products-and-candidacy

cosmesis. (n.d.) *Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing, and Allied Health, Seventh Edition*. (2003). Retrieved April 20 2024 from https://medical-dictionary.thefreedictionary.com/cosmesis

Darc Piculo dos Santos, A., Ferrari, A. L. M., Medola, F. O., & Sandnes, F. E. (2020). Aesthetics and the perceived stigma of assistive technology for visual impairment. *Disability and Rehabilitation: Assistive Technology*, *17*(2), 1–7. Taylor & Francis Online. https://doi.org/10.1080/17483107.2020.1768308

Ellington, T., & Lim, S. (2013). Adolescents' Aesthetic and Functional View of Hearing Aids or Cochlear Implants and Their Relationship to Self-Esteem Levels. *Fashion Practice*, *5*(1), 59–80. https://doi.org/10.2752/175693813x13559997788763

Elsherif, M., Moreddu, R., Alam, F., Salih, A. E., Ahmed, I., & Butt, H. (2022). Wearable Smart Contact Lenses for Continual Glucose Monitoring: A Review. *Frontiers in Medicine*, *9*. https://doi.org/10.3389/fmed.2022.858784

Englefield, J. (2022, October 10). *Sangyu Xi designs Airy scoliosis brace for teenagers to be worn "with confidence."* Dezeen; Dezeen. https://www.dezeen.com/2022/10/10/sangyu-xi-airy-scoliosis-brace-teenagers-confidence

Everett, C. (2023, November 15). *How to Choose a Hearing Aid: Types and Styles* (L. Banks, Ed.). NCOA Adviser; National Council on Aging, Inc. https://www.ncoa.org/adviser/hearing-aids/hearing-aid-types-styles/

Faraji, A., & Kasiri, M. (2013). SIP: Smart Insulin Pump. *Applied Mechanics and Materials*, *464*, 123–128. ProQuest. https://doi.org/10.4028/www.scientific.net/amm.464.123

Farrington, C. (2016). Wearable technologies and stigma in diabetes: the role of medical aesthetics. *The Lancet Diabetes & Endocrinology*, *4*(7), 566–566. https://doi.org/10.1016/S2213-8587(16)00075-9.

Geyer, M., Seymour, F. K., Stott, L., Lynch, C., Beukes, M., Aleksy, W., & Graham, J. M. (2006). How we do it: Patient participation in cochlear implant selection. *Clinical Otolaryngology*, *31*(1), 56–61. https://doi.org/10.1111/j.1749-4486.2006.01127.x

GN Consumer Hearing Corporation. (2024). *Enhance Select 100*. Jabra Enhance; Jabra Enhance. https://www.jabraenhance.com/product/enhanceselect100

González, J. C., Olaso, J. M., Gil, M. H., Puigcerver, S. A., Durá, J. V., & Lopez, I. (2012). FASHION-ABLE: Needs and requirements for clothing, footwear and orthotics of consumers groups with highly individualised needs. *2012 18th International ICE Conference on Engineering, Technology and Innovation*. IEEE Explore. https://doi.org/10.1109/ice.2012.6297700

Hallwachs, A. J., Weinstein, J. E., & Reilly, B. K. (2018). Cochlear implant symmetry via template. *International Journal of Pediatric Otorhinolaryngology*, *105*, 40–42. https://doi.org/10.1016/j.ijporl.2017.12.002

Hanky Pancreas. (2024). *Products*. Hanky Pancreas. https://shop.hankypancreas.com/

Harper, A., Aflatoony, L., Wilson, W., & Wang, W. (2020). Exploring the Challenges and Potential Alternatives to Insulin Pump Technologies. *Proceedings of the 14th EAI International Conference on Pervasive Computing Technologies for Healthcare*, 371–374. ACM Digital Library. https://doi.org/10.1145/3421937.3421950

Harris, J. E. (2019). The Aesthetics of Disability. *Columbia Law Review*, *119*(4), 895–972. https://www.jstor.org/stable/26632274

Hazelton, M. J., McCarthy, G. M., & Rodríguez Ramírez, E. R. (2019). The semantics of conspicuity: Design strategies to address conspicuity in type 1 diabetes medical devices for adolescents. *DeSForM19 Proceedings*. DeSForM 2019. https://doi.org/10.21428/5395bc37.6c683e08.

hearX Group. (2024). *Lexie Lumen*. Lexie Hearing. https://lexiehearing.com/us/lexie-lumen-hearing-aid

Hilton, K., Jones, F., Harmon, S., & Cropper, J. (2013). Adolescents' Experiences of Receiving and Living With Sequential Cochlear Implants: An Interpretative Phenomenological Analysis. *Journal of Deaf Studies and Deaf Education*, *18*(4), 513–531. https://doi.org/10.1093/deafed/ent025

Hng, T., & Burren, D. (2018). Appearance of Do‐It‐Yourself closed‐loop systems to manage type 1 diabetes. *Internal Medicine Journal*, *48*(11), 1400–1404. Wiley Online Library. https://doi.org/10.1111/imj.14105

Hussain, S. (2011). Toes That Look Like Toes: Cambodian Children's Perspectives on Prosthetic Legs. *Qualitative Health Research*, *21*(10), 1427–1440. SageJournals. https://doi.org/10.1177/1049732311411058

Karia, D., Nambiar, R. S., & Arora, M. (2019). An Affordable Insulin Pump for Type-1 Diabetic Patients: A Case Study of User-in-the-Loop Approach to Engineering Design. *Proceedings of the Design Society: International Conference on Engineering Design*, *1*(1), 847–856. Cambridge University Press. https://doi.org/10.1017/dsi.2019.89

Krabbe, A. D., & Grodal, S. (2018). Big, Beige and Bulky: Aesthetic Shifts in the Hearing Aid Industry (1945-2015). *Proceedings - Academy of Management*, *2018*(1), 14487–14487. https://doi.org/10.5465/ambpp.2018.222

Krabbe, A. D., & Grodal, S. (2023). The Aesthetic Evolution of Product Categories. *Administrative Science Quarterly*, *68*(3), 734–780. https://doi.org/10.1177/00018392231173677

Lahoud, D., Teng, C. H., Nusem, E., Burns, J., Wrigley, C., & Cheng, T. L. (2020). Content analysis of child user and carer perspectives of ankle–foot orthoses. *Prosthetics & Orthotics International*, *45*(1), 12–19. https://doi.org/10.1177/0309364620952906

Lal, R. A., & Leelarathna, L. (2023). Insulin Delivery Hardware: Pumps and Pens. *Diabetes Technology & Therapeutics*, *25*(S1), S-43. Mary Ann Liebert, Inc Publishers. https://doi.org/10.1089/dia.2023.2503

Lang, A. R., Martin, J. L., Sharples, S., & Crowe, J. A. (2013). The effect of design on the usability and real world effectiveness of medical devices: A case study with adolescent users. *Applied Ergonomics*, *44*(5), 799–810. ScienceDirect. https://doi.org/10.1016/j.apergo.2013.02.001

Laubner, K., Singler, E., Straetener, J., Siegmund, T., Päth, G., & Seufert, J. (2019). Comparative Dose Accuracy of Durable and Patch Insulin Pumps Under Laboratory Conditions. *Diabetes Technology & Therapeutics*, *21*(7), 371–378. Mary Ann Liebert, Inc Publishers. https://doi.org/10.1089/dia.2019.0089

Law, D., Cheung, M., Yip, J., Yick, K.-L., & Wong, C. (2016). Scoliosis brace design: influence of visual aesthetics on user acceptance and compliance. *Ergonomics*, *60*(6), 876–886. Taylor & Francis Online. https://doi.org/10.1080/00140139.2016.1227093

Lebenthal, Y., Lazar, L., Benzaquen, H., Shalitin, S., & Phillip, M. (2012). Patient Perceptions of Using the OmniPod System Compared with Conventional Insulin Pumps in Young

Adults with Type 1 Diabetes. *Diabetes Technology & Therapeutics*, *14*(5), 411–417. Mary Ann Liebert, Inc Publishers. https://doi.org/10.1089/dia.2011.0228

Lucid Hearing. (2024, March 19). *Enrich Pro BTE*. Lucid Hearing. https://lucidhearing.com/product/enrich-pro-bte/

Luximon, Y., Shah, P., & Iftikhar, H. (2019). Aesthetic Considerations in the Ortho-Prosthetic Design Process. *Conference Proceedings of the Academy for Design Innovation Management*, *2*(1). https://ira.lib.polyu.edu.hk/bitstream/10397/90139/1/a0733-n02_1207.pdf

Macadam, C., Barnett, J., Roberts, G., Stiefel, G., King, R., Erlewyn-Lajeunesse, M., Holloway, J. A., & Lucas, J. S. A. (2012). What factors affect the carriage of epinephrine auto‐injectors by teenagers? *Clinical and Translational Allergy*, *2*(1). https://doi.org/10.1186/2045-7022-2-3

Martin, J. L., Murphy, E., Crowe, J. A., & Norris, B. J. (2006). Capturing user requirements in medical device development: the role of ergonomics. *Physiological Measurement*, *27*(8), R49–R62. https://doi.org/10.1088/0967-3334/27/8/r01

Matthews, M., & Wynne, J. (2021). The Use of a Dynamic Elastomeric Fabric Orthotic Intervention in Adolescents and Adults with Scoliosis. In J. Bettany-Saltikov & G. Kandasamy (Eds.), *Spinal Deformities in Adolescents, Adults and Older Adults* (pp. 59–83). IntechOpen. https://books.google.com/books?id=HJYtEAAAQBAJ&pg=PA59

McCarthy, G. M., Rodríguez Ramírez, E., & Robinson, B. J. (2017). Letters to medical devices: A case study on the medical device user requirements of female adolescents and young adults with type 1 diabetes. In P. deVries, H. Oinas-Kukkonen, L. Siemons, N. Beerlage-de Jong, & L. van Gemert-Pijnen (Eds.), *Persuasive Technology: Development*

and Implementation of Personalized Technologies to Change Attitudes and Behaviors (pp. 69–79). Springer International Publishing. https://link.springer.com/chapter/10.1007/978-3-319-55134-0_6

McKee, P. R., & Rivard, A. (2011). Biopsychosocial Approach to Orthotic Intervention. *Journal of Hand Therapy*, *24*(2), 155–163. ClinicalKey. https://doi.org/10.1016/j.jht.2010.08.001

Medtronic. (2013, July 31). *Myth vs reality: Insulin pumps and continuous glucose monitors*. Medtronic Diabetes. https://www.medtronicdiabetes.com/loop-blog/myth-vs-reality-insulin-pumps-and-continuous-glucose-monitors

Migirov, L., Taitelbaum-Swead, R., Hildesheimer, M., Wolf, M., & Kronenberg, J. (2009). Factors Affecting Choice of Device by Cochlear Implant Candidates. *Otology & Neurotology*, *30*(6), 743–746. https://doi.org/10.1097/mao.0b013e3181b285bd

O'Kane, A. A., Rogers, Y., & Blandford, A. E. (2015). Concealing or Revealing Mobile Medical Devices? *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/2702123.2702453

Orliman. (2024, March 27). *Home*. Orliman. https://www.orliman.com/filtro-avanzado/

Pals, R. A. S., Hviid, P., Cleal, B., & Grabowski, D. (2021). Demanding devices – Living with diabetes devices as a pre-teen. *Social Science & Medicine*, *286*, 114279. ScienceDirect. https://doi.org/10.1016/j.socscimed.2021.114279

Park, J. W., & Cho, S. (2011). Metamorphosis: An Aesthetic Approach to Orthosis Design. *Design Principles and Practices: An International Journal—Annual Review*, *5*(5), 277–290. https://doi.org/10.18848/1833-1874/cgp/v05i05/38191

Peterson, P. (2023). *Is My Pancreas Showing? Insulin Pumps As An Extension To The Body. Wearable Tech And Identity And The Creation Of A Community* [Thesis]. https://doi.org/10.32920/23546211.v1

Pimp My Diabetes. (2024). *Show off your devices with style!* Pimp My Diabetes. https://pimpmydiabetes.com/

Portnova, A. A., Mukherjee, G., Peters, K. M., Yamane, A., & Steele, K. M. (2018). Design of a 3D-printed, open-source wrist-driven orthosis for individuals with spinal cord injury. *PLOS ONE*, *13*(2), e0193106. https://doi.org/10.1371/journal.pone.0193106

Profita, H. P., Stangl, A., Matuszewska, L., Sky, S., & Kane, S. K. (2016). Nothing to hide: Aesthetic customization of hearing aids and cochlear implants in an online community. *ASSETS '16: Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*, 219–227. https://doi.org/10.1145/2982142.2982159

Profita, H. P., Stangl, A., Matuszewska, L., Sky, S., Kushalnagar, R., & Kane, S. K. (2018). "Wear it loud": How and why hearing aid and cochlear implant users customize their devices. *ACM Transactions on Accessible Computing*, *11*(3), 3. https://doi.org/10.1145/3214382

Pump Peelz. (2024, March 29). *Personalized Insulin Pump and CGM Patch Designs*. Pump Peelz. https://pumppeelz.com/

Punch, R., & Hyde, M. (2011). Social Participation of Children and Adolescents With Cochlear Implants: A Qualitative Analysis of Parent, Teacher, and Child Interviews. *Journal of Deaf Studies and Deaf Education*, *16*(4), 474–493. https://doi.org/10.1093/deafed/enr001

Rachmiel, M., Levy-Shraga, Y., Gruber, N., Orit Pinhas-Hamiel, Barash, G., Dikla Pivko-Levy, & Landau, Z. (2019). Comparing Insulin Pump Devices in Real Life: The AWeSoMe

Study Group Prospective Experience. *Diabetes Technology & Therapeutics*, *21*(3), 138–145. Mary Ann Liebert, Inc Publishers. https://doi.org/10.1089/dia.2018.0309

Rapport, F., Chi Yhun Lo, Elks, B., Warren, C., & Clay-Williams, R. (2022). Cochlear implant aesthetics and its impact on stigma, social interaction and quality of life: a mixed-methods study protocol. *BMJ Open*, *12*(3), e058406–e058406. https://doi.org/10.1136/bmjopen-2021-058406

Rentschler, C., & Nothwehr, B. (2021). Transmitting Insulin: The Design and Look of Insulin Delivery Devices as Technologies of Communication. *Catalyst: Feminism, Theory, Technoscience*, *7*(1), 1–36. Catalyst. https://doi.org/10.28968/cftt.v7i1.34567

Ritholz, M. D., Smaldone, A., Lee, J., Castillo, A., Wolpert, H., & Weinger, K. (2007). Perceptions of Psychosocial Factors and the Insulin Pump. *Diabetes Care*, *30*(3), 549–554. American Diabetes Association Publications. https://doi.org/10.2337/dc06-1755

San Pedro Orozco, P., Blaya Haro, F., Campoy Quintana, P., Blaya San Pedro, A., D'Amato, R., & Juanes, J. A. (2019). Aesthetics in orthopedic products: Applications of the advanced manufacture (AM) to the industrial design of orthoses. *TEEM'19: Proceedings of the Seventh International Conference on Technological Ecosystems for Enhancing Multiculturality*. 372–379. https://doi.org/10.1145/3362789.3362826

Sansoni, S., Speer, L., Wodehouse, A., & Buis, A. (2016). Aesthetic of prosthetic devices: From medical equipment to a work of design. In S. Fukuda (Ed.), *Emotional Engineering Volume 4* (pp. 73–92). Springer International Publishing. https://doi.org/10.1007/978-3-319-29433-9%E2%82%85

Sansoni, S., Wodehouse, A., & Buis, A. (2014). The Aesthetics of Prosthetic Design: From Theory to Practice. *DS 77: Proceedings of the DESIGN 2014 13th International Design Conference.* 975-984. https://www.designsociety.org/publication/35242/THE+AESTHETICS+OF+PROSTHETIC+DESIGN%3A+FROM+THEORY+TO+PRACTICE

Scheiner, G. (2012). Matching Patients to Devices: Diabetes Products Are Not One-Size-Fits-All. *Clinical Diabetes*, *30*(3), 126–129. American Diabetes Association Publications. https://doi.org/10.2337/diaclin.30.3.126

ScoliosisPTJax. (2020, January 8). *Can A Scoliosis Brace Help with Adolescent Idiopathic Scoliosis*. ScoliosisPTJax. https://www.scoliosisptjax.com/will-a-brace-help-with-my-childs-scoliosis/

Sonnenberg, M. [@mike_sonnenberg]. (2017a, August 13). *"I finished the first Blog entry, have a Look. Link is in bio #placingyou #bloggerlife #ohrschmuck #hearingaids #phonak #widex #resound #signia #earmolds #hearingloss #handcrafted"* [Photograph]. Instagram. https://www.instagram.com/p/BXvsD74B53O/

Sonnenberg, M. [@mike_sonnenberg]. (2017b, April 24). *"#schmuckotoplastik #custommade #earmolds #ohrschmuck #hearingaids #hörschmuck #hearingaids #hörgeräte"* [Photograph]. Instagram. https://www.instagram.com/p/BTRa_WhAFic/

Type One Style. (2024). *Shop Premium Diabetes Patches, Stickers & Cases*. Type One Style. https://www.typeonestyle.com/en-us

Wilde, D., & Marti, P. (2018). Exploring Aesthetic Enhancement of Wearable Technologies for Deaf Women. *DIS '18: Proceedings of the 2018 Designing Interactive Systems Conference*, 201–213. https://doi.org/10.1145/3196709.3196777

Yetisen, A. K., Moreddu, R., Seifi, S., Jiang, N., Vega, K., Dong, X., Dong, J., Butt, H., Jakobi, M., Elsner, M., & Koch, A. W. (2019). Dermal Tattoo Biosensors for Colorimetric Metabolite Detection. *Angewandte Chemie International Edition*, *58*(31), 10506–10513. https://doi.org/10.1002/anie.201904416