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The Assistive Wearable: Inclusive by Design

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Abstract

Wearable technology has the potential to usher in a new wave of assistive technology. Many wearable devices are already being used by people with disabilities as assistive technology. Here we discuss how designers might use design considerations and body maps to make sure that the wearable devices they are creating are accessible to everyone. The hope is that, with a thoughtful process, new wearable technology can also act seamlessly as assistive technology.

Keywords: wearable technology, design guidelines, design process

Introduction

Wearable technology, in its many forms, following the path of smartphones, is rapidly becoming a part of everyday life (Abowd, Tech, & Mitchell, 2005; Morris, Jones, & Sweatman, 2016). New forms of wearable technology have all kinds of uses and can be worn on many different parts of the body. These wearable devices not only sync with our smart phones, but increasingly are able to establish a wide variety of wireless connections to give quicker and more meaningful interactions with information. The creators of the first wave of smart phones may not have incorporated accessibility as a driving factor of design, a condition which was addressed via policy-making and regulatory interventions, and subsequently is part of the current development approach. (Baker & Bellordre, 2004; Baker & Moon, 2008; Mitchell et al., 2004). In fact, developers of wearable technology are increasingly taking into account accessibility and usability, and consequently, enhancing a wearable device's use as assistive technology (Oliver, 2017). As such, these design objectives become a key factor influencing marketability.

Assistive technology applications have been developed using the smart phone's inherent multimodal display and input capabilities (Frey, Southern, & Romero, 2011; Morris & Mueller, 2014; John Morris, Mueller, & Jones, 2014). One of the most important uses of assistive smartphone applications can be lifesaving in emergency situations, as noted by Mitchel and Lucia (Mitchel & Lucia, 2014) , who outline a number of considerations for accessible emergency communications. In terms of important design parameters, technological considerations focus on *developing or providing accessible formats to disseminate alerts and information,* and to *manufacture cost effective, universally designed devices.* The usefulness of wearable devices could have the same assistive functionality, especially if accessibility considerations are incorporated into the early stages of the design process.

To aid designers in the process of developing inclusive wearable technology, we have developed a set of *Body Maps* that include design and accessibility considerations for placement and use of wearable technology (Zeagler, 2017a, 2017b). The information contained in the *Body Maps* is based on a synthesis of over 100 academic papers from the last 50 years on how technology can be and should be worn on the body for optimal use.

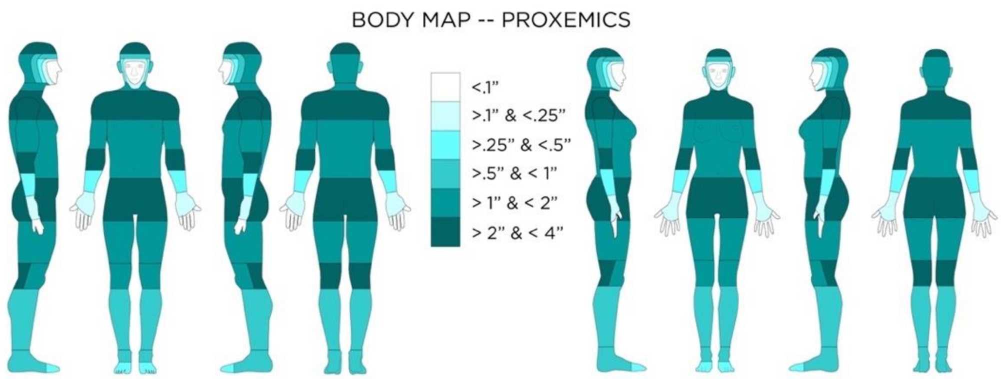
Target Audience and Relevance

The primary target audience for the design considerations and *Body Maps* described in this paper includes developers and designers of wearable technology. We anticipate that those with specific aims of creating wearable assistive technology would search and find the information presented here to be a useful tool. Ultimately, our hope is that all those who design wearable technology might begin the design process with a better understanding of how the choices they make affect the accessibility, and more broadly, the usability of the wearable devices they create.

New Tools for Inclusive Design: Body Maps and Wearable Placement

What follows is a list of considerations that designers and creators of wearable technology should take into account as they develop wearable products. These considerations are organized by the requirements of certain types of on-body technology with respect to the types of sensing and input/output the systems utilize, and the locations where devices might be worn on the body. The *Body Maps* are diagrams of the human body with regions highlighted where appropriate on-body devices might be worn. We specifically highlight here device *Accessibility Considerations*, a subset of a more robust list of the design considerations developed by Zeagler (Zeagler, 2017a, 2017b). Some information (such as thermal tolerances) are dictated by the human body, while others (such as networking) are limitations in technology when combined with the human body. Many of the wearable lessons incorporated within the *Body Maps* come from insights generated while developing assistive technology (Ghovanloo & Huo, 2014), and a large majority of the design considerations have direct impact on the design of new assistive technology. The maps were graphically generated from older diagrams, or descriptions within the academic texts as interpreted by an expert in wearable technology.

Proxemics



BODY MAP 1 – Proxemics Map - Proxemics as defined here is a human's perception of self-size. The distance from the body portrayed on this body map indicates how far from the body a wearable device might extend and still be naturally considered part of the person's self-size awareness. Items extending beyond this distance from the body might take a period of time for a person to adjust and account for the object within their personal self-size envelope.

Proxemics, as defined here (Body Map 1), is a human's perception of self-size. The distance from the body portrayed on this body map indicates how far from the body a wearable device might extend and still be naturally considered part of the person's self-size awareness. Items extending beyond this distance from the body might take a period of time for a person to adjust and account for the object within their personal self-size envelope. Gemperle proposes proxemics as a consideration for "Design for Wearability" (Gemperle, Kasabach, Stivoric, Bauer, & Martin, 1998). Edward T. Hall illuminates a humans' relationship to the space around them in *The Hidden Dimension* (Hall, 1990). Gemperle borrows Hall's definition of intimate space at 0-5 inches to create an envelope around the body of the user's perceived body size.

A *Body Map*, then, is produced by taking this perceptual envelope and segmenting it into zones. Using these zones, we can make suggestions of where to place wearable technology based on the distance that tech extends from the body. We also incorporated the clothing corrections guide from Henry Dreyfuss Associates "The Measure Of Man and Woman" as a proxemics minimum guide as most humans wear clothing (Tiley & Henry Dreyfuss Associates, 2001).

Accessibility Considerations for Proxemics

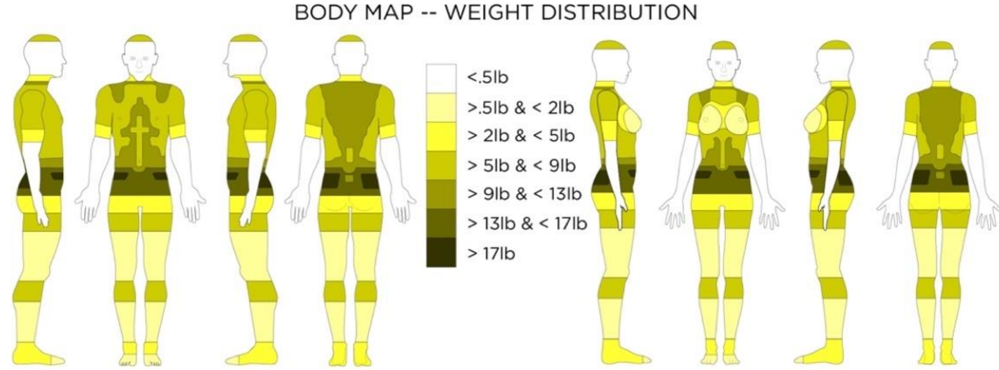
- Someone with a body limitation that requires the use of a wheel chair (or other assistive device) may have a much different self-perceived size that would include their assistive device and normal posture.
- Attachments to a required assistive device will also affect proxemics, and should be viewed as a "wearable".

Weight Distribution

The weight of wearable objects matter, and heavier items can be carried by the body more comfortably in some locations than others. In the 1970s, while the US army was designing body armor, researchers were tasked with developing a system for finding load thresholds of discomfort (Scribano, Bruns, & Baron, 1970; Watkins, 1995).

> "In general, the army found that the fleshy parts of the body were more able to tolerate the pressure of weight than the bony ones, and that pressure on major nerves, arteries, and veins, particularly those that supply the brain, can affect coordination, and produce fatigue." (Watkins, 1995 pg 259).

The body map shows the amount of weight or pressure that can be placed on the area before the pressure becomes a discomfort.

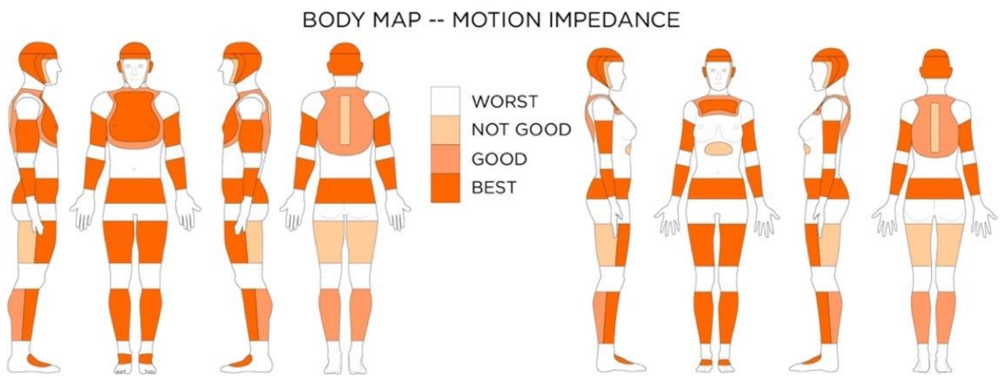


BODY MAP 2 – Weight Distribution Map - This body map shows the amount of weight, or pressure that can be placed on the area before the pressure becomes a discomfort.

Accessibility Considerations for Weight Distribution

- Watkins states: *"One aspect of Load Analysis to consider is that even though these tests provide data on pressure levels, not all individuals or areas of the body respond in the same way to pressure. Age, sex, medical conditions and other factors may affect the way in which pressure affects mobility."* (Watkins, 1995 pg 259.)
- Of course, it is easy to assume that designers want the most light weight wearable technology anyway, but it is also good to remember that being light weight can make the wearable technology useful to broader communities (the elderly, individuals with a range of medical conditions, children, etc.)

Body Mechanics and Movement



BODY MAP 3 – Zones of Motion Impedance - This body map shows the best places to put wearable devices on the body, where they will be the least obtrusive and cause the least amount of body motion impedance.

Gemperle's main observation with respect to body movement was that wearable devices should not be placed on or inside joints (Gemperle et al., 1998). Roebuck created a system for describing body movement in the 1960s while developing space suits for NASA (Roebuck, 1968). Roebuck's system of linkages, when combined with Henry Dreyfuss and associates' (Tiley & Henry Dreyfuss Associates, 2001) standard range of motions charts, gives us a solid foundation for creating the Body Map of Motion Impedance. The body map shows the best places to put wearable devices on the body: where they will be the least obtrusive and cause the least amount of body motion impedance.

Design Considerations for Body Motion

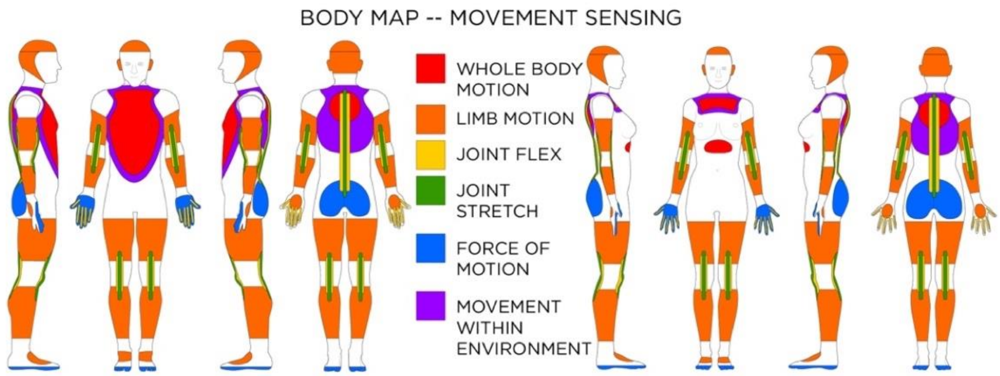
- Large, bulky, or rigid objects should not be placed on the inside of joints, or the concave areas where the body bends.
- Rigid objects or flexible but non-elastic objects should be adhered to the outside of joints in a way that hinders the skin on the outside of the joint from stretching.
- Smart garments, clothing, or e-textiles should have ample room, or flexible and elastic properties to allow all parts of the body to move effectively.

- Larger or rigid objects should be located in zones on the body with relatively limited movement or linkages.

Accessibility Considerations for Body Motion

- All body movement criteria should apply the same to individuals with impaired self-movement, unless the wearable is specifically designed to stabilize the body for medical purposes.
- Individuals may be unable to feel or move parts of their body, but these body parts still have the capability of movement from outside sources. This means that a discomfort from an inappropriately placed wearable device will not be felt, and could cause harm from extended wear.

Movement Sensing Consideration



BODY MAP 4 – Movement Sensor Placement - For sensing whole body motion, and limb motion, accelerometers, gyroscopes, and magnetometers can be used at locations indicated. For sensing joint movement, flex or stretch sensors can be used at locations indicated. Force can explain the impact of movement. If trying to capture movement within an environment, magnetometers (for direction) and barometric pressure sensors (for elevation change) may be used.

Understanding the body's movement through space and relative to itself is one of the main motivations behind wearable technology (Aminian & Najafi, 2004; Kramer, 2000; Zeagler, Starner, Hall, & Wong Sala, 2015). For sensing whole body motion and limb motion, accelerometers, gyroscopes, and magnetometers can be used at locations indicated. For sensing joint movement, flex or stretch sensors can be used at locations indicated. Force can explain the impact of movement. If trying to capture movement within an environment, magnetometers (for direction) and barometric pressure sensors (for elevation change) may be used.

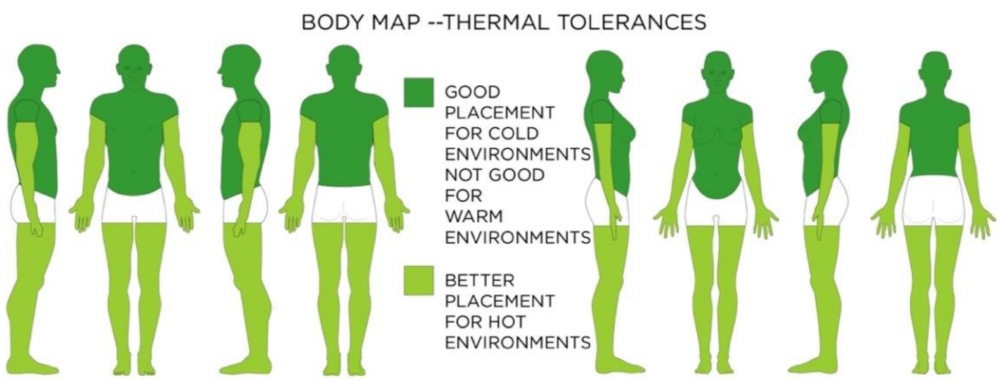
Wearable technology used to determine how a person is moving can have a huge impact on assistive use. Sensors can help determine acceleration, walking/steps/running, and even posture (Farringdon, Moore, Tilbury, Church, & Biemond, 1999; Karantonis, Narayanan, Mathie, Lovell, & Celler, 2006; Sekine, Tamura, Togawa, & Fukui, 2000; Yang & Hsu, 2009). Pressure sensors under the foot can help explain how a person steps and distributes weight (Godbout &

Boyd, 2010), and stretch resistance sensors placed over knee joints could aid in rehabilitation exercise adherence (Byrne, Rebola, & Zeagler, 2013). Walking and gait sensors can be used monitor improvements of individuals with movement challenges. Kuo et al. used ankle mounted accelerometers to measure walking and steps of children with cerebral palsy (Kuo, Culhane, Thomason, Tirosh, & Baker, 2009). Accelerometers and gyroscopes placed on the head might be able to tell balance, head tilt, head turning, and even falling (Lindemann, Hock, Stuber, Keck, & Becker, 2005).

Accessibility Considerations for Movement Sensing

- On-body motion/movement sensors can be a great noninvasive way to monitor someone who has a disability or is "aging in place." Because the movement sensing can be complete and complex, but also can be done without respect to location there is a level of privacy.
- Depending on body-placement of the movement sensors whole body motion, or specific body motion can be obtained. If monitoring someone for mobility a whole-body movement sensor placed at the chest might be used to see if an aging person is "getting around". If a person is in rehabilitation from knee surgery, perhaps a movement sensor on the knee might be used to see if they are complying with their exercises.

Thermal Tolerances



BODY MAP 5 – Zones of Thermal Tolerance - This body map shows where to place wearable technology (which adds heat through operation and added bulk and material). This map focuses on a device's tendency to raise overall body temperature; however, tissue on the body can burn at any location if exposed to enough heat over time.

The Body Map of thermal tolerances shows where to place wearable technology (which adds heat through operation and added bulk and material). This map focuses on a devices tendency to raise overall body temperature; however, tissue on the body can burn at any location if exposed to enough heat over time.

Design Considerations for Thermal Tolerances

- In a hot environment, a wearable "should be non-conductive (so the heat from the environment or heat produced by the wearable is not conducted to the body).” (Watkins, 1995)

- In a hot environment a wearable should “allow air to circulate as freely as possible over the skin surface (to aid convective cooling and evaporation of sweat).” (Watkins, 1995)
- “Allow freedom of movement (to prevent any extra physical effort that would increase metabolism).” (Watkins, 1995)
- In a hot environment, a wearable “should provide minimum coverage or maximum ventilation for the body core.” (Watkins, 1995)
- In a cold environment, the heat produced by the wearable could be directed towards the body for extra warmth. (Watkins, 1995)
- Do not allow devices to exceed 105°F at any time when next to the skin.
- A temperature of 111.2°F for 7 hours next to the skin can cause a second or third degree burn.

Accessibility Considerations for Thermal Tolerances

- Those with sensory disabilities could be highly susceptible to burns from wearable devices, and as such, temperature sensors should be placed in wearable devices with cut off mechanisms.
- Multimodal displays including lights and sound should be used to warn of overheating. Again, if a person cannot feel a localized heat source at the body location where the wearable is placed, even lower temperatures over longer time periods can cause significant burns.

Biometric Sensing Consideration

Biometric sensing could greatly enhance the assistive application of wearable devices. Biometric sensors work best on specific locations on the body. There are many kinds of biosensors that sense different types of biosignals. Pantelopoulos and Bourbakis completed a survey of sensors on the market in 2008 and 2010 (Pantelopoulos & Bourbakis, 2008, 2010). The main types of biosignals that need to be monitored are vital signs; including heart rate, blood pressure, temperature, respiration, blood glucose, perspiration, and brain activity. There is a body map associated with each of these biosignals to aid designers in placing wearable technology (Zeagler, 2017a).

Design Considerations for Biometric Sensing

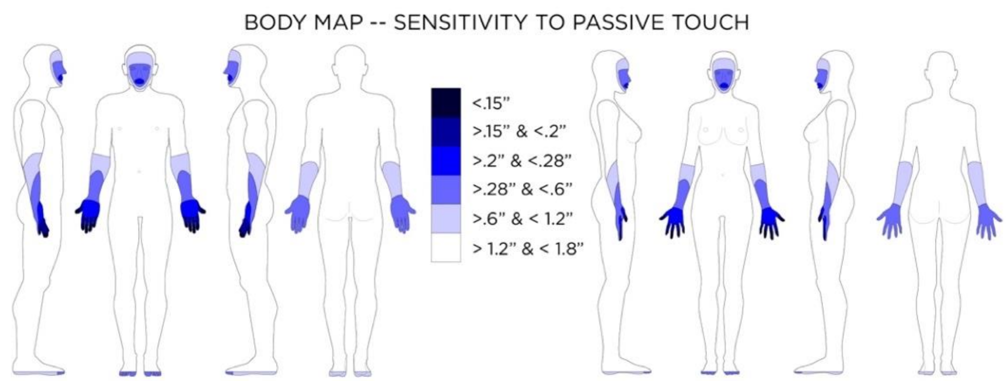
- Heart Rate / Heart Movement ECG sensors tend to be located on the chest near the heart. The more precise measurement needed the more body area these electrode-based sensors will cover.
- Stimulation/Perspiration/Hydration sensors can be placed anywhere on the body with correct calibration, and thus should come secondary in body placement to other sensors packaged with them. These sensors need direct contact with the skin.

- Blood Pressure sensors and PPG Heart Rate sensors should be placed where blood vessels are close to the surface of the skin. These sensors also need direct contact with the skin.
- Blood Glucose sensors that have a subdermal port tend to be located at the waist (perhaps for ease of supporting the external electronics on the waistband). Other types of Blood Glucose monitors are located at the source of bodily fluid they are utilizing for sensing.
- Respiration monitors generally strap around the chest and measure chest volume change (they tend to be paired with a simple ECG to collect heart rate).
- EEG Sensors have to be placed on the scalp/forehead to measure brain activity.

Accessibility Considerations for Biometric Sensing

- Designing wireless wearable technology for collecting important biometric data might be one of the best ways to allow those who need to have constant monitoring an accessible and free lifestyle.
- New glucose monitor designs that do not require a subdermal port are less invasive, but might not yet collect data with the desired accuracy and reliability needed in some cases.
- EEG sensors that are mobile and wireless offer up great potential in accessibility, especially for “locked in” patients. These sensors might not be accurate enough yet for medical use. (G.Tec Medical Engineering, 2017)
- Choices in body location of biometric sensing for impaired individuals need to both work for the biosensor to collect data and for the mobility/reachability of the individual.

Tangible / Tactile / Haptic Feedback (passive touch)



BODY MAP 6 – Body Sensitivity to Passive Touch - Average distance in two-point discrimination sensitivity test on body locations.

A large number of wearable devices use vibration to act as a notification. People’s sensitivity to *passive touch* not only differs across the body, but also differs between people. It is important to know where the body is most sensitive so designers can make decisions about vibration notification. This is especially important for assistive technology, where sensitivity to *passive touch* could have even greater variances in the population.

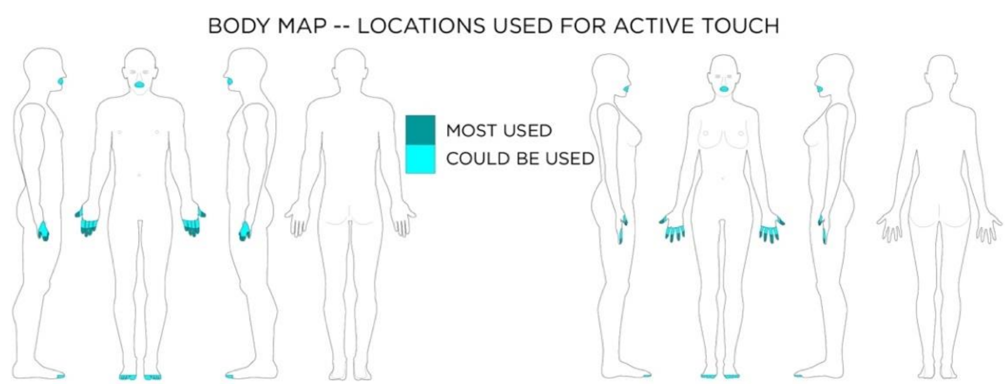
Design Considerations for Tangible / Tactile / Haptic Feedback (passive touch)

- When designing haptic displays for wearable devices, the sensitivity of the on-body location where the wearable is placed is very important.
- Vibrotactile displays should be programmed to account for masking and vibrotactile adaptation.

Accessibility Considerations for Tangible / Tactile / Haptic Feedback (passive touch)

- Tangible/Haptic Feedback is an important part of a multimodal display system. Multimodal feedback is important; designers need to create wearable devices that can prompt users with a variety of different abilities. Vibration and haptic alerts can aid those with visual impairments when acoustic feedback is inappropriate.
- Vibration and haptic feedback have been seen to provide added benefit in rehabilitation of injuries (such as spinal injuries) where sensation has been degraded. Mobile Music Touch has shown that rehabilitation with the vibrating piano gloves not only taught participants to play piano, but also improved their sensation and dexterity (Markow et al., 2010).

Touch (Active Touch)



BODY MAP 7 – Body Used for Active Touch - Active touch represents the exploratory action of touching.

“Active touch represents the exploratory action of touching, which is generally involved with kinesthetic movement of the body.” (Gibson, 1962; S. Lee, 2012 pg 14). Creating interfaces that are “easy to find” through active touch is essential for wearable interfaces. Norman talks a great deal about mapping associated with physical interfaces (Norman, 2013), but the shape of buttons and levers offer affordances as well, and our hands find a way of using them through active touch. A good example would be a cylinder with ridges for grip on the side, as it affords turning.

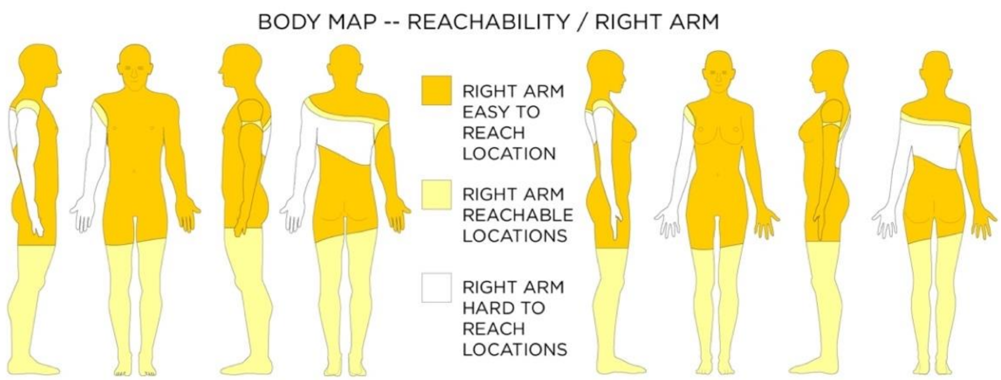
Design Considerations for Active Touch

- Following good human factors and industrial design standards when creating physical interfaces will aid in a person's ability to use active touch to interact with objects and controls. This is also true for interfaces on the surface of wearable devices.
- Certain shapes contain certain affordances. Concavities on top of buttons might lend themselves to a pushing type active touch investigation. Ridges on the circumference of cylinders might lend themselves to turning. Expenditures at an angle to a plane might afford a flick or leverage. Dreyfus lays out shapes and sizes for controls in his book (Tiley & Henry Dreyfuss Associates, 2001).

Accessibility Considerations Active Touch

- It is important to remember that each person has a different ability to feel or sense tactile sensation. Thus, interfaces should be designed with robust multisensory feedback. Whereas one person might feel a click of a button through tactile means, others who cannot might require an audio cue or a visual cue to know that a selection has been made.

Reachability



BODY MAP 8 – Map of Ease of Reach of Body Locations – Right Arm - When it comes to reach-ability there are easy-to-reach locations (where your hand can reach without any body movement), reachable locations (where you can move a part of your body to your hand to be able to reach it), and hard to reach locations (such as your center back).

Being able to reach a wearable device is important for interacting, but also for donning and doffing the device. When it comes to reachability, there are easy to reach locations (where your hand can reach without any body movement), reachable locations (where you can move a part of your body for your hand to be able to reach it), and hard to reach locations (such as your center back), as well as *duration* of reachability (Vatavu, 2017)

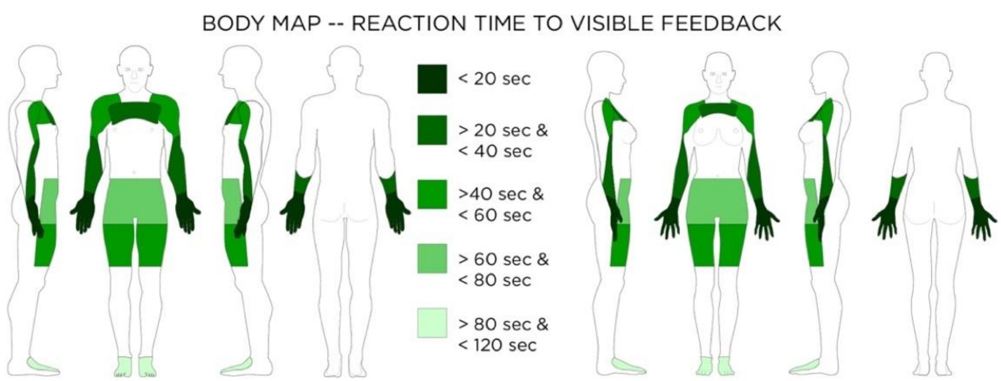
Design Considerations for Reachability

- Wearable Devices should be placed in easy-to-reach on-body locations, especially for interfaces, but also for donning and doffing.

Accessibility Considerations Reachability

- Reachability is very personal as people have different physical abilities with respect to body movement.
- It is best to design a wearable device that does not cater to a dominant body side (right / left) and also is easy to reach with the hand's extension.
- Some people who spend most of their time in a seated position might be able to reach their upper thighs to their knees more readily. It might be better however to design wearable devices useful to everyone in the same way.

Visible Feedback



BODY MAP 9 – Visible Body Areas Map - Average reaction time to visible feedback.

In 2009 Chris Harrison developed a study to decide where on the body visible feedback would be noticed the easiest (Harrison, Benko, & Wilson, 2011; Harrison, Lim, Shick, & Hudson, 2009; Harrison, Ramamurthy, & Hudson, 2012). LED lights were used to create a system where the user was asked to push a button at the light whenever the light was illuminated. This gave an individual's reaction time to seeing the visible feedback. The body map for visible body areas from a first-person perspective also takes into account Harrison's reaction times; therefore, the map is more representative of where a designer should locate a wearable visual display, rather than just locations where a user can see it.

Design Considerations for Visible Feedback

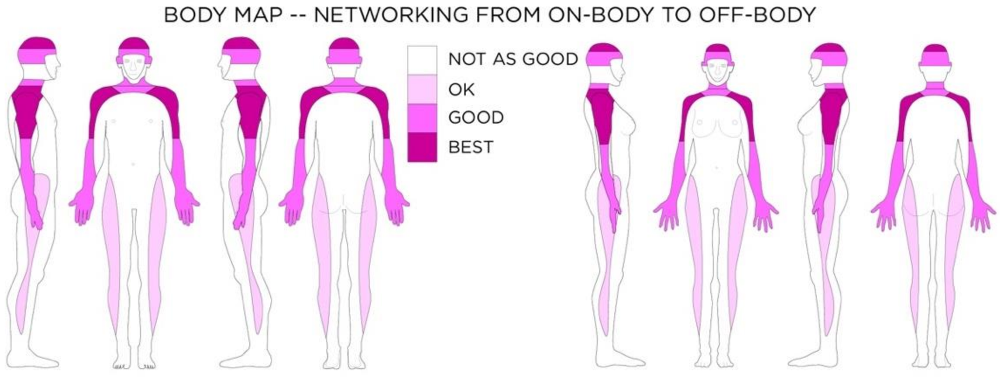
- When designing a wearable device with a display or visual signal, it is important that the device be placed on a part of the body where the display can be seen, and also a place on the body where it will be noticed easily.

Accessibility Considerations for Visible Feedback

- Visual displays should be accompanied by non-visual signals for those with visual impairments.
- The visibility of on-body locations might change from person to person depending on their

mobility and means of mobility. Wheelchairs or other mobility devices might occlude some on-body locations which would otherwise be acceptable for a visual display.

Networking on the body



BODY MAP 10 – Networking from the Body Map - This body map shows the areas on the body where a network antenna (to communicate to the fixed off-body wireless frequencies) could be placed to have the least chance of signal interference by the mass of the body.

Thad Starner (2001) claimed networking as one of the major challenges of wearable computing.

> *For wearable computers, networking involves communication off body to the fixed network, on body among devices, and near body with objects near the user. Each of these three network types requires different design decisions. Designers must also consider possible interference between the networks* (Starner, 2001 p. 54).

When considering on-body location, designers need to consider the location of the antenna that communicates with the off-body fixed network. The mass (water/muscle/tissue) of the body can block many of the lower-powered high-frequency wireless network signals we use for communication (S. P. Hall & Hao, 2006). At a higher power, such frequencies could have the potential to cause tissue damage, which is unacceptable for wearable devices.

> *Wireless Body Area Networks (WBANs) experience high path loss due to body absorption that must be minimized through heterogeneous and multi-hop links with different types of sensors at various locations. Additionally, change in operational conditions may lead to error-prone and incomplete sensor data relative to inherent sensor limitation, human postures and motions, sensor breakdown and interference.* (Movassaghi, Abolhasan, Lipman, Smith, & Jamalipour, 2014, p. 1679).

There is a balance, and many people have researched the application of WBANs for medical and other wearable sensing systems (Hanson et al., 2009; Patel & Wang, 2010; Ullah et al., 2012). The body map shows the areas on the body where a network antenna (to communicate to the fixed off-body wireless frequencies) could be placed to have the least chance of signal interference by the mass of the body.

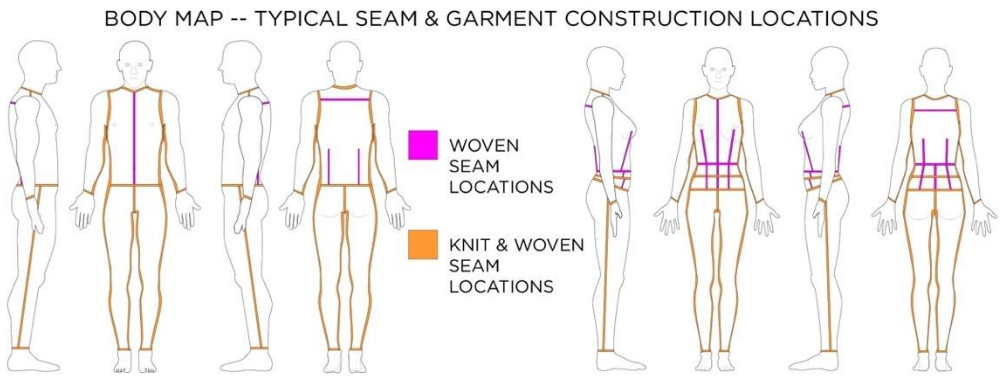
Design Considerations for Networking

- Antennas for wearable devices should be placed on the periphery of the body to have the best chance of having an unobstructed (by the body) connection to the fixed off-body network. This could mean the outer arms, shoulders, or the head. Because of the strength and abundance of fixed off-body wireless network signal, this is not as much of a problem as it would have been in 2001.
- Body Area Networked devices using low-powered wireless connections between devices on the body should also try to avoid obstruction by the body between devices. If one device on the front torso for example needs to wirelessly communicate via low powered signal to a device on the back, a third relay might be needed on the side of the body.
- All body mass compositions are unique. Outside of the general guidelines, wearable systems using wireless communication should be tested thoroughly on a variety of people and in a variety of settings.

Accessibility Considerations for Networking

- Health monitors or wearable sensing devices use Body Area Networks. Some people might have many different monitors all using different frequencies. It is important when designing a new device that it does not interfere with wearable health devices such as heart monitors or pace makers. It is also important that it does not interfere with wireless hearing aids and other assistive devices. Adding a new signal to a series of signals requires some standards, research, and testing.

Manufacturing for Garments



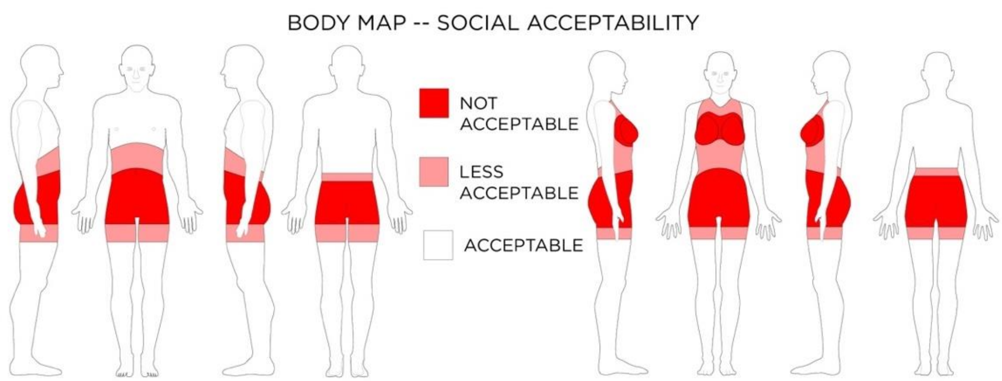
BODY MAP 11 – Typical Seam Locations and Other Garment Construction Locations

A little knowledge of fabric and garment manufacturing goes along way when designing wearable technology meant to be incorporated into clothing. A simple concept is that fabric stretches and wiring does not. Patterns can be changed to accommodate sensors that need to be placed on certain body locations (Jones, 2005; Joseph-Armstrong, 2000; Watkins, 1995; Watkins & Dunne, 2015). It is better to place wires and leads in the seams of garments that run vertical with the body rather than horizontal to the body. It is also important to account for how electronics will change the drape of clothing. Importantly some textile manipulation techniques can lend themselves to fabric interfaces (Gilliland, Komor, Starner, & Zeagler, 2010; Komor et al., 2009; Lee, Shin, Starner, Gilliland, & Zeagler, 2016; Wolff, 1996; Zeagler, Gilliland, Audy, & Starner, 2013; Zeagler et al., 2017; Zeagler, Gilliland, Profita, & Starner, 2012), and some couture sewing techniques might sometimes be used for the hand work necessary in creating some wearable technology (Shaeffer, 2001).

Accessibility Considerations for Garment Manufacturing

- Some garments are specifically designed to be donned and doffed by people with mobility issues (Watkins, 1995; Watkins & Dunne, 2015). Designing wearable systems for incorporation with these garments should follow the same strategies as any other garment. However, if redesigning seams and closures to afford the wearable technology incorporation, it is important not to impede the donning and doffing functionality of the accessible garment.

Social Acceptability



BODY MAP 12 – Social Acceptability Body Map - Social acceptability of on-body touch based interactions.

The gestures and touches users make with wearable technology to interact and control devices can cause unanticipated social reactions. This can also be especially true for people with disabilities, who might not want to draw attention to their use of assistive technology. Certain onbody placements of interactive textiles, interfaces, and the types of gestures used to control these interfaces can make a wearer/user, as well as onlookers, feel awkward. “For wearable devices, the social perception and comfort of worn artifacts often extends beyond the “static” aesthetic variables of the artifact (worn on the body, but not interacted with) into the social aesthetics of interacting with a body- worn device,” (Dunne et al., 2014; Dunne, Profita, & Zeagler, 2014). Profita et al. look specifically at body placement of interactive electronic textiles and how third-party viewers deem interactions socially acceptable when placed on different parts of the body (Profita et al., 2013).

Accessibility Considerations for Social Acceptability

- Sometimes users want assistive technology to be conspicuous so that others know about their needs. Other times users want wearable technology to be inconspicuous so they can go about their daily life without a disability being the focus. Designers should work with users to allow for wearing technology in ways that can throttle the visibility of wearable assistive technology.
- Wearable assistive technology should conform to the same social acceptability standards as other wearable technology. Assistive devices do not have to look like medical devices.

Using Body Maps and Design Considerations within the Design / Development process

The design process is iterative, but a good place to start is with an initial assessment of the needs of the users of any designed object, and wearable technology devices have a good deal of aspects to consider. By giving designers and developers a set of accessibility considerations (and *Body Maps* of on-body locations where these considerations might take hold in wearable technology) within the larger usability context, at the beginning of the process, designers are more likely to remember the broad spectrum of users including those who might use wearable technology in an assistive manner. The seven principles of universal design are a good example of how such principles considered at the outset of a design project can have a huge effect on the eventual design (Ross & Affairs, 2001).“The seven principles also provide useful guidelines on how wearable computer interface designers can broaden their systems' appeal in the general population, just as Alexander Graham Bell's invention of the telephone while pursuing the concept of a hearing aid for his wife” (Gandy, Ross, & Starner, 2003). Guidelines, affordances, and considerations help design teams form parameters and create a design brief for developing products.

In previous work, we have considered how the outcomes of iterations in the wearable technology design process could affect policy, and how policy considerations in turn could affect design (Baker, Gandy, & Zeagler, 2015; Gandy, Baker, & Zeagler, 2016). Figure 1 describes how design and accessibility considerations could be included in the iterative process, directly before design ideation takes place. If designers have some guidance before ideation, it helps to not only avoid technical pitfalls (perhaps from mislocating a sensor on the body), but also to help in designing more universally accessible devices. It can also have an effect on the types of “use case ideation and visualization” designers decide to scenario when thinking through design decisions. It would be helpful to diversify the range of potential users, including people with disabilities and other functional limitations, when visualizing wearable technology use cases.

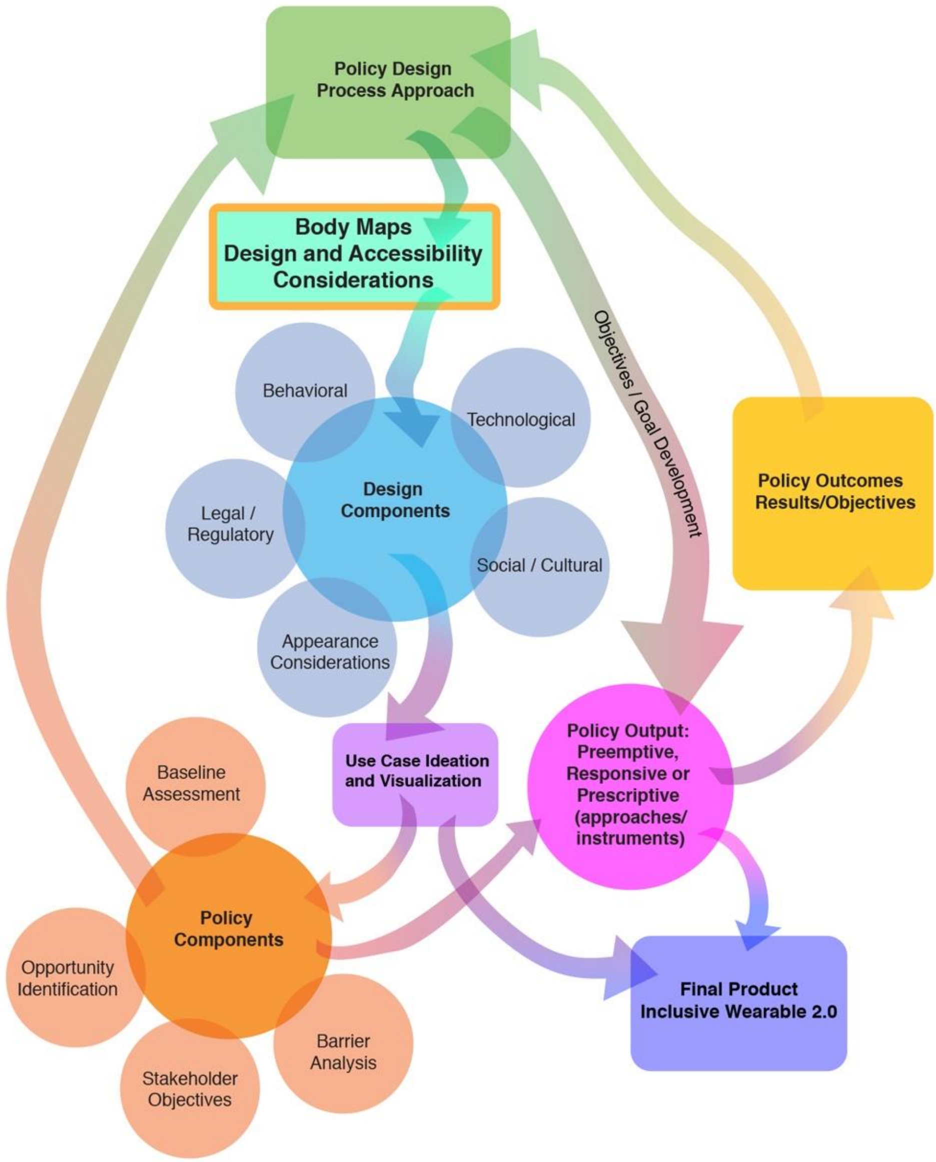


Figure 1. Incorporating Body Maps and Accessibility Considerations into the collaborative policy wearable technology design framework. (Baker et al., 2015; Gandy et al., 2016)

Use Case Scenario

Fatimah and her design group are charged with designing an application/interface for a wearable device that serves in a cognitive assistive function (e.g. reminders, calendar entries, guidance), health monitoring as well as to provide emergency alerting. Fatimah's group has great knowledge in mobile applications and designing task management apps, but has never designed wearable technology before and do not really know where to get started. Fatimah does some initial research and comes across the *Body Maps* design and accessibility considerations for wearable technology. Fatimah's group has not in the past been generally concerned with accessibility of their mobile applications; however, a new colleague has a family member with increasing physical challenges, and he brought this (the need for accessibility) to the attention of the group as a potential design objective. Fatimah and her group use the *Body Maps* and design considerations to decide with the rest of the device development team the inter-relationship between device placement and interface design. Fatimah realizes that application notifications made through the wearable device should work for the largest set of people possible and some of those people will have a variety of disabilities.

As they begin to design the app interface for the wearable, they decide they want a screen and visual display (which helped in deciding on-body location because of visibility), and they also want to include an auditory display for notifications. They decide to include a vibration display; this helps with notifications, but also creates a multimodal notification system which could be especially useful to people who might have a hard time noticing one of the other display formats. They also take into account the placement of sensors needed to provide body data, for which the *Body Maps* proved to be of great help. After they complete their first design iteration, Fatimah and her group start to visualize how the early prototype could be used. In one visualization, a team member imagines a scenario where there is a disaster and people use their device along with Facebook's Safety Check feature to let their loved ones know they are ok, and where they are. Remembering the design accessibility considerations, Fatimah decided to invite potential users with disabilities to a series of design conversations to explore potential opportunities, desired capabilities and use barriers, and to probe on ways to make sure this feature is also easy to use for those with disabilities because it is related to safety. Fatimah and her team go back through a design iteration with this feature in mind. Following this, Fatimah develops some simulations which are tested with the target user group and which are observed by the larger wearable device team. The users were especially interested as they had not before had the opportunity to see how their input was actually included in the development process, and the larger device design team was interested in observing how an inclusive design process could actually solve some problems they had not even thought of.

Current Assistive Technology Devices Analyzed Against Body Map Guidelines

There many devices on the market that it might be illuminating to look at through the lens of the *Body Maps* design guidelines and accessibility considerations. For simple example, we could look at the use of hearing aids. The ear affords hearing, and therefore it seems the obvious place for a hearing aid. As most hearing aids are inner ear, they fit within the proxemic thresholds for that area of the body. Hearing aids are light weight. They do not impede movement or create large amounts of heat. They are easy to reach and therefore easy to don and doff. Hearing aids are also socially acceptable to interact with due to the proliferation of earbuds and headphones used for listening to media.

A set of wearables that might not hold as well to analysis against the *Body Maps* guidelines are those surrounding diabetes management. Continuous Glucose Monitors CGMs are attached with a port into the fatty area of the skin, they send a wireless signal to a remote and display that must be kept on the body. Insulin pumps have a port that also must be attached to a fatty area of the body. The pumps mechanics can either be attached directly to the skin in a small housing with wireless communication to a controller, or via a small tube to the pump mechanics and controller. In either case, the small displays and mechanics need to be worn on the body. Depending on placement, even these small devices can get in the way. Proxemics around the back of the arm (where they are sometimes placed) can be precarious for devices. There is also a huge social obstacle to interaction at the normal placement of ports and equipment as well. Interacting with interfaces on the waste can be awkward in public (which is why many in the DYI diabetes community use smartphones or smart watches for CGM notifications and pump controls). There are even undergarments for evening wear to help hide the wearable components of CGMs and insulin pumps while at a formal event.

Some of the issues surrounding the design of CGMs and insulin pumps are hard to overcome because of technical requirements or the affordances of the human body. However, through the use of the *Body Maps* design guidelines and accessibility considerations, many of the issues could have been illuminated early in the development process. With this knowledge designers can adapt designs for flexible use, allowing the wearer to accommodate their unique and individual needs.

Outcomes and Benefits

We anticipate that the design considerations and *Body Maps* presented here will serve as a resource for designers developing wearable technology. We believe that if designers incorporate this knowledge into the development of wearable technology, it will be more accessible, as well as having greater assistive utility for those who might need it. A logical next step for the project could be to make this information more available through development of a web tool for designers to use to be able to explore initial choices in the design process, pointing them on an inclusive design path. This web tool could aid in choosing where on the body to place wearable devices, how to make wearable devices more accessible, and also how to create everyday devices that also act as assistive technology. Wearable technology and similar connected devices have the potential to become a game changer for people living with disabilities, but optimal use would flow from the inclusive design of technology that is accessible, usable, and sensitive to the variety of needs of the end users.

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