Provisional chapter

Creative Haptic Interface Design for the Aging Population

Eric Heng Gu

Additional information is available at the end of the chapter

Abstract

Audiovisual human-computer-interfaces still make up the majority of content to the public; however, haptic interfaces offer unique advantage over the dominant information infrastructure, particularly for users with a disability or diminishing cognitive and physical skills like the elderly. The tactile sense allows users to integrate new, unobstructive channels for digital information into their sensorium, one that is less likely to be overwhelmed compared to vision and audition. Haptics research focus on the development of hardware, improving resolution, modality, and fidelity of the actuators. Despite the technological limitations, haptic interfaces are shown to reinforce physical skill acquisition, therapy, and communication. This chapter will present key characteristics intuitive tactile interfaces should capture for elderly end-users; sample projects will showcase unique applications and designs that identify the limitations of the UI.

Keywords: haptic interface, tactile user interface, HCI, UI/UX, aging population, assistive technology

1. Introduction

Our society has been designed to be sight dominated. Information is typically presented graphically; human-computer interaction (HCI) research under-represents the needs of users with disabilities. Particularly for the elderly with diminished cognitive and motor skills, graphical user interfaces further hamper their ability to adapt to new technology. Interfaces specifically designed to engage the other sensory organs are promising alternatives. The haptic and auditory senses for example are more suitable for intuitively extracting meaningful patterns from big data. Sonification as a data processing method has had success in a number of industries, most notably NASA's application on solar flare data [1]. Even a layman can listen to the transmuted data and pick out the rhythms of solar activity. These modalities also suffer less from fatigue than visual displays and benefit from tolerance, which filters out unimportant steady-state data and highlights anomalies. This chapter will discuss specifically the design of haptic interfaces for the aging population, while drawing examples and inspiration from other fields.

By 2050, an estimated 2 billion people will be over the age of 60, with 20% suffering from a mental or neurological disorder [2]. In Japan, a projected 25% of the population will be above 65 by 2020 [3]. In the United States, a projected $17 trillion in Medicare expense will be necessary to cope with the rapidly growing segment of the population over 65. High costs associated to therapy for dementia, Alzheimer's, and other neurological conditions [2]. Digital technological illiteracy coupled with growing societal isolationism and sedentarism severely hamper their ability to engage socially, leading to negative impacts on mental wellbeing. Loss of income, partners and friends, mobility, and sense of purpose are risk factors to health, resulting in lowered quality of life. We hope to investigate the design of technology that enhances the lives of the elderly, specifically projects that capture the following characteristics of HCI in haptic interfaces:

1.1. Immersion

Effective simulation of a realistic environment, given technological limitations, to capture essential elements or within unique contexts.

1.2. Animacy

Conveyance the qualities an animate being (abstract feelings, i.e., presence, intimacy, and pleasantness), on top of basic sensory information and mechanical characteristics.

1.3. Affordance

Inclusive, intuitive UI design for and consistent communication of possible usage.

As technology improves, higher fidelity simulations will be available, but conscious design for extreme users is still necessary. To put it simply, if individuals are struggling to perform in the real world due to their physical and cognitive limitations, then they would be equally disadvantaged in a precise simulation of the real world. Artificial generation and selective curation of sensory information based on the needs and preferences of the user is the goal. Haptic technology is far from creating precise representation of reality. At best, it can be intuitive in its conveyance or takes advantage of pre-existing quirks of our brain. This chapter will showcase examples of haptic interfaces with novel, creative designs and/or implementations that bypass the technological limitations of the devices, with a particular focus on their potential for elderly users. The word creativity in this context implies some novelty in its design and/or application, particularly highlighting designs that exploit existing quirks in our haptic perception.

2. Background on haptic processing

Haptic interfaces as assistive technology gained prominence in the 1960s with the discovery of neuroplasticity and became a promising modality for treating patients with disabilities. The term "Sensory Substitution" coined by Paul Bach-y-Rita to describe the method of replaces a missing or ineffective sensory input with one that is functional [4]. This requires the translation of one form of information into another; Bach-y-Rita et al. created BrainPort to investigate the translation of visual information for the blind into electro-tactile stimuli supplied to the tongue [4]. Other examples of sensory substitution as a non-invasive technique is used in projects like haptic-vest for the deaf (sound-to-touch) [13], and sonic-glasses for the blind (sight-to-sound) [5]. Progress in sensory substitution for the disabled overlap with the elderly with diminishing sensory capabilities.

We already use substitution as a treatment for age-related diseases. Age-related macular degeneration is a condition that plague predominately individuals over 60; one of its remedies is an Implantable Miniature Telescope that refocuses the light from the damaged portion of the retina to less-damaged portions originally used for peripheral vision [6]. This is substitution within the same sensory organ, swapping damaged center of vision for the better functioning peripheral vision.

Haptic interfaces facilitate the development of motor skills, [paper on training motor skills using haptic interfaces]. We investigated physical skill acquisition in sports like archery, and explored the use of haptic interfaces to establish a closed-loop system for training muscle memory [7]. Instead of requiring the visual confirmation of proper posture, the haptic feedback informs the user through vibration patterns. Our brain integrates redundant information from multiple sensory organs to accelerate learning; thus, haptic feedback is frequently supplemented onto existing modalities. Telepresence physiotherapy with mediated touch is found to be more engaging and effective than visual instructions alone [8].

Cross-modal applications are also more compelling to our sensorium; haptic perception is heightened when coupled with other sensory inputs (proprioception, vision, audition). The haptic illusion of a texture is more powerful when the vibrotactile sensations are provided and synchronized with the movement of the participant's finger [9]. The ventriloquism effect [10] is an example of cross-modal stimuli forming a compelling unified perception of disparate visual and auditory information.

Researchers have been steadily improving the qualities of haptic actuators, which fall into several major categories, from most commonly used to least: (1) vibrotactile actuators, (2) electro-tactile actuators, (3) compressive/deformation (air-sacs, solenoids, etc.), (4) fluid mediums. Despite a steeper familiarity curve than other senses, haptic interfaces have several advantages. Specifically in application for the elderly with diminishing cognitive functions, the clutter of visual and auditory information become overwhelming and cause fatigue over time. Evaluation of visual, auditory, and multi-modal displays for elderly drivers (mean age 68) show that additional visual information led to less safe driving due apparently to higher demand on attention, with multi-modal being reportedly the most comfortable and useful [11].

We believe that the only limitation to immersive simulations are the quality of actuators. Mimicking reality is therefore not the focus of this chapter. Instead, we will discuss creative applications of haptic interfaces in terms of the types of experiences they allow for, given the technological constraints. Most of these fall under "haptic illusions" that our sensorium constructs. As a researcher, creating these powerful haptic experiences is most often a process of discovering an existing neurological phenomenon.

Our experience of haptic information in the real world is almost always coupled with other senses, predominantly vision and proprioception. Haptic sensation itself is also vibration [12], same as audition. By connecting spatial information and haptic sensation, the tactile nature of the target is generated internally. The discovery of frequency nature of haptic stimuli, we are able to create better simulations drawn from reality. Recording and playing back textures for example has a wide range of applications from more immersive telepresence and VR experiences to very specialized utility tools for designers [9]. However, in designing tactile displays, the goal need not be to reproduce known phenomenon; the brain can learn and adapt to new interfaces with new intentions. Simplest forms of haptic interfaces of binary activation (ON or OFF) is easiest to learn. By augmenting this information temporally and/or spatially, much more complicated information can be sent to the brain. In the case of sensory substitution, Eagleman Lab showed that the deaf can make use of temporal–spatial, vibrotactile stimuli to decipher auditory input of spoken words [13]. Similar methodology applied on abstract datasets, such as stock market [14], further supports the power of neuroplasticity to adapt.

3. Haptic interface design

The main focus of haptic technology development is to produce higher resolution and higher fidelity of actuators that improve simulation quality. Applications of this technology give designers versatility to conjure immersive realities or surrealities. The electrotactile feedback to simulate virtual walls [15] is a literal representation of reality; projects like the electromagnetic shoes simulating dynamic gravity [16] offer other worldly realities. There are also unique haptic interfaces allow for very specialized applications, such as Microsoft's HapticLink, a bimanual controllers [17] that are connected and can simulate stiffness of operating two-handed objects (i.e., operating keys of an instrument, shooting a bow, etc.). Wearable haptic device like the Microsoft's Claw [18] and EXIII's Exos wrist DK [19] both use servos to provide resistance to your palm and fingers to "touch" digital shapes.

Specialized embodiments of the design, like dynamically deformable surfaces (i.e., ForceForm) can vary in stiffness (simulate lumps, indents) to facilitate telepresence diagnosis [20].

Rather than simulating reality, "haptic special effect" are similar to sound effects in movies. The Star Wars lightsaber sounds, which have no real world counterpart, are recorded with metal wires slapping against a hard surface. When paired with appropriate visual and/or auditory stimuli, haptic illusions can be very compelling. The iconic cutaneous bunny-hop illusion involves several point source of tactile actuators on a subject's arm; when triggered in sequence, the brain's change bias combines the separate sources into one moving source

[21]. An evolution of the illusion, the "/ed" (slashed) project by Watanabe et al. creates the illusion of being sliced in half with haptic feedback coupled with seeing a fake sword slash [22]. Speakers in front of the subject triggers, followed by those on the back, giving the subject a sensation of object passing through the body.

The gaming industry makes use of haptic illusions to supplement their gameplay. REZ's Synesthesia suit uses vibrotactile feedback to enhance the psychedelic visual and auditory gaming experience [23]. The overload of multi-modal stimulation is suitable in the context of the game. The KOR-FX haptic vest recreates a reduced version of bullet impact [24]. Disney Research's haptic chair does not reproduce the sensation of driving, but its vibrotactile actuators can influence and possibly supplement the spatial awareness of the player [25].

The elderly are found to be more receptive toward haptic than visual interfaces [26]. Since the first graphic user interface appeared, the windows, icons, menus, and pointing device (WIMP) design has not changed. All current GUIs are derivatives of the original concept and build off of users' prior experience with them. It is possible that as the part of the population that grew up with technology and are familiar computing esthetics age, this will change. For the currently and imminently senior population, metaphorical UI and association with tangible objects from real life are much more approachable [27]. Immersive simulations can offer a new life for those with reduced mobility. "Second-life" platforms are making a comeback as a result of VR technology [28]. Through design and improvements in technology, immersion can be powerful enough to trigger our body image plasticity that allows for remapping of motor controls and development of new habits. From remapping of existing nerves to operate a prosthetic arm [29], to EEG-enabled direct brain-computer interaction by a monkey [30], the brain demonstrates profound adaptivity in reaction to the new interfaces.

Neuroplasticity and increase in brain matter have been observed in elderly subjects tasked with learning a new motor skill for 90 days (juggling & navigation games) [31], with apparent delay of Alzheimer's [32]. These improvements, however, were seen to disappear after 90 days of inactivity, implying the need for continued intervention [31]. Therefore, the design of interfaces that accompany the elderly need to be engaging enough for continued usage, or risk atrophy and difficulties in relearning. In the following sections, we will present some key characteristics to designing haptic interfaces for the elderly with diminishing cognitive and motor functions.

3.1. Animacy

Animacy is a subcategory of Immersion that deserves highlighting. If Immersion can be seen as providing enough information to make a simulation compelling, then Animacy is conveying enough information to make sentient elements believable or imbue traits of sentience. Tactile information is crucial to the expression of emotion in humans and animals [34], and to the formation of social bonds [35]. We can even form these intimate bonds with inanimate objects when the right stimuli are present; symphonic musicians respond emotionally to the haptic feedback from their instruments [36].

Social isolation and sedentarism are becoming more rampant. As the population ages alongside this shift, the elderly are more likely to be living independently and in isolated situations. Reduced mobility lead to reduced social interactions, so telepresence communication is becoming the dominant way for comprehensive communication. While our information infrastructure make this possible already, a larger amount of data can be designed into the interaction to enhance the Animacy of the communication partner. One study shows that haptic stimuli provided in conjunction with audio clips of conversations enhanced our perception of the conversations' qualities (more animate, pleasant, warm, etc.) [37]. However, the influence of the stimuli is not reported by the participants, despite observed differences when compared to a control group [37]. Similarly, the inclusion of haptic qualities of a conversation in telecommunication is often overlooked when designing immersive experiences, despite their powerfully persuasive effects. Essential to the conveying sense of emotional intensity and Animacy, haptic telepresence, or mediated touch, is a crucial piece of telepresence technology [38].

CASPER by Tokyo University effectively uses haptic telepresence (air-cannon) to transmit instructor's touches to parts of the participant's body; some of the participants of the experiments noted that they could feel the presence of the instructor there with them [8]. Some elderly participants even shared their desire to have remote interactions with family and friends through the device [8]. By successfully capturing Animacy through mediated touch, we can mitigate the problems caused by social isolationism and sedentarism. These solutions can also be easily augmented onto existing platforms and other modalities.

Daily interpersonal communication make use of physical contact to convey and receive haptic sensations that inform on the emotional state and animacy of others. Rigid correlation between stimuli and resulting abstract feelings has not been drawn, but the presence, not the content, of haptic stimuli reveal a non-trivial impact on the quality of communication [37]. Nevertheless, we have found that temperature, pressure and frequency of haptic outputs are important characteristics to triggering emotional responses in the user. Changes to initial body temperature affect subjects' emotional response measured with skin conductance response (SCR); higher ratings of arousal and dominance are reported with contact to a pre-adjusted temperature source than through dynamically adjusting the contact to a target temperature [37]. The same study suggests that warmer or colder stimuli do not matter, while other literature suggests warmer stimuli are associated with pleasantness [39, 40]. A larger range of temperature thresholds is necessary to trigger avoidance and approach behaviors. Pressure is a common modality for conveying emotion, such as its use to comfort children with autism [33]. Temporally supplied stimulation is another powerful indicator: with low frequency of feedback are linked to stronger feelings of intimacy, and higher frequencies correlate to anxiety. Commercial devices such as Doppel have been built under the premise that our body's rhythms can be influenced by an external stimulus. Doppel operates by vibrating at particular frequencies that appear to influence wearer's heart rate [41].

Haptic feedback in telepresence situations offer unique interactions to capture non-verbal communications. Haptic pajamas that allow parents to remotely hug their children [42]. The Pebble smartwatch transmits intensity of activity (body motion) between two people through vibration [43]. User feedback for Pebble confirmed a sense of animacy and presence of their partners. Interestingly, the users combined their knowledge of the partners with the device. For instance, when the Pebble is outside the range of internet and stops transmitting, the receiver could tell their partner had entered the subway and felt reassurance when the signal re-appeared [43]. Reassurance does not have to come from a human source; Keio University's Nene projects uses a soft robot avatar of the participants' pets to study effect of haptic telepresence on loneliness [44]. The pet cats' or dogs' body temperature is reproduced in the doll, as are the sounds they make; purring is translated to vibration sensations. Compared to the control group, subjects report a decrease in loneliness over the 2 weeks of usage. The thermal, auditory, and vibrotactile stimuli produced a sense of Animacy and presence of the pet, which had a calming effect on the subjects [44]. It would be interesting to investigate whether the existence of a real-world source of the stimuli is crucial to the calming effect, or that an algorithm generated simulation of the pet is enough. The following section will discuss telepresence therapy and design for elderly in more detail.

3.2. Affordance

Physical and cognitive impairments are rising alongside the growing life expectancies of an aging population. Visual and auditory deficiencies affect the sufferer's ability to engage with much of the predominated infrastructures. Deterioration of cognitive and motor skills mean that the elderly have lowered independence and mobility, leading to decreased quality of life. Technology driven solutions in virtual reality (i.e., Rendever) and artificial intelligence [45] can mitigate some of these problems, but their designs likewise underrepresented this demographic. Virtual reality in particular offer advantages for the elderly: (1) simplified, safe, simulated space for learning, therapy, and exploration, (2) adaptive, responsive modalities based on user's requirements and preferences. Comparable to solutions for people with disabilities or autism, these technological interventions for the elderly face the challenge of dealing with minority population of extreme or unique users. Thus, one solution is not enough for the variety of contexts, but bespoke solutions are costly. Affordances in the design of UI for these technologies can have life changing impacts.

Just as visual and auditory VR have shown to help with people with physical [46], sensorial [47], and cognitive [48] disabilities, haptic feedback enhances activities like rehabilitation, learning, and behavioral change. Stroke victims regaining motion benefit from visual and haptic feedback in their training process [46]. Memory retention and information acquisition is enhanced by haptic layer of redundancy, as we found in our work on multi-modal reading [49].

Redundancy is a powerful tool in designing UI for extreme users. Especially for novel UI elements, redundant conveyance through multiple modalities can make learning easier. In the conditions that they work, jet pilots require haptic feedback in order to effectively operate their vehicles [50]. Haptic helmets and chairs are used to offer a level of redundant information on the state of their aircraft when the other senses (proprioception, vision, audition) are unreliable or unavailable. Elderly users can benefit from a similar technique of redundancy to supplement their diminishing senses: navigation for the blind through a haptic belt [51], and for the elderly through augmented reality [11] are some examples. Movement rehabilitation

[8] and motor skill learning especially benefit from the haptic feedback. However, the designer needs to be conscious of the different needs and offer affordances in their product for the extreme users.

The term "Affordance" arose from psychology and later adopted by HCI as the consistency between possible actions and the user's perception of the possibilities. Dan Norman expanded on the definition in his book "*The Design of Everyday Things*" [52] to perceived versus real affordances. Unlike the perceived affordances of GUI design for visual displays, real affordances do not require the user to have a preconceived notion about an element's function. Visual interfaces in our products often build off of user's prior digital literacy and familiarity. A graphical representation of a button requires you to understand the nature of its real world counterpart; a dropdown menu is a mutation of the button that do not have a physical analog to draw prior knowledge from. For the elderly and extreme users, we should not design with reliance on domain-specific conventions and consistencies, which they may have neither the familiarity with nor the capability of using. Our interview with elderly PACE participants in the United States reveal their preference of Kindle over smart-tablet devices because of the former's affordances for viewing content, yet apps for the elderly are still predominantly on the latter. We highlight three main challenges for the elderly subjects to using haptic interfaces, which can be overcome with Affordances designed into the device.

3.2.1. Learning/familiarity curve

The most challenging aspect of learning a new haptic interfaces is need to experience the interface first-hand; an intellectual demo is often not enough. Instead, the user must try it out, which also adds difficulty for the iterative design process. The learning curve can be lowered through design. By taking advantage of our instincts and other senses, we can encode haptic information in intuitable ways. For instance, animals and insects make use of the haptic sense to construct their mental model of the world around them [53]. Biomimetic design for sensory augmentation such as Tokyo University's Haptic Radar demonstrates the effectiveness of intuitive haptic stimuli to trigger responses with no training [54]. The radar is a good example of affordance due to its simplicity: haptic feedback equates to the presence of an obstacle which triggers user reaction. There is alternative interpretation possible. A notable product for the elderly that achieves this are the emergency alert devices (i.e., MobileHelp, Lifeline). It is a simple button that transmits a signal to the emergency response facilities; particularly useful for the elderly in independent-living situations, the device allows for only singular purpose that is intuitable even when the user is confused or in duress.

Inspired by the mnemonic device of "memory palaces" in cognitive psychology [55], we created a virtual reality memory box, Keepsake, to explore the retrieval of memory using spatial coordinates around the user [56]. The association of a life event with a general direction relative to the body was a preferable alternative to the linear timeline of most graphic displays. Likewise, physical objects enhance recall: asking an elderly subject to recount memories regarding a souvenir have much more detailed responses than without the physical aide [57]. Metaphorical UIs are powerful tools for guiding intuition, as long as the users are already familiar the metaphor. In the context of design for extreme users and technologically illiterate, analogies from culture and psychology are more reliable starting points than established UI design practices.

Social learning is the theory that we observe and learn from others' behavior. Our mental model of another's mind and action help us inform our own. Therefore, collective, group learning is another useful technique for reducing the familiarity curve. Keio University Fujisawa et al. experimented with a group of participants learning to operate artificial tails [58]. Some group of participants were allowed to communicate with each other and share their discoveries. In those groups, the experiment identified a cascade effect in which proficiency rapidly spread through all participants when a single individual discovers a breakthrough.

3.2.2. Malfunctions and failures

All technology can malfunction. The results of malfunction or failures in systems we heavily rely upon can cause detrimental results for the user. In the case of telepresence devices that are linked to the user's partner (Pebble) or pets (Nene), a severed connection can cause unnecessary stress over their perceived condition. Reviews for the commercial devices like the BOND bracelet that allow users to send "touches" to a partner is a good example of technical failure causing severe emotional responses [59]. Designers need to clearly indicate to the user of system failure rather than something catastrophic on the other end of the telepresence. If the BOND bracelet could have informed the user the difference between a problem with the app or device and a problem with the partner, customers may be more forgiving with technical difficulties. More serious cases of technology that enable certain actions or aide motion require special attention: unexpected failures in haptic feedback in devices helping the elderly with activities like maintaining balance or navigation can have dangerous consequences. Failsafes must be implemented prior to unsupervised usage.

3.2.3. Personalization and diversity of needs

One of the greatest barriers to the proliferation of this technology is the diversity of extreme user needs. Variations in body types and deficiencies require bespoke and often singular solutions, thus significantly increase the costs for development. The field of prosthetics design for the physically disabled face a similar problem. Body type difference and varying needs means one design cannot have full coverage. Techniques like crowdsourcing and rapid-prototyping have been a boon for prosthetics design and can likewise be useful for haptic interfaces. Developers of products should look upstream, prior to the actual usage, to implement ways to grant wider access for extreme users.

In the case of prosthetics, makers are creating bespoke solutions from off the shelf components [60]. Open-sourced platforms (i.e., OpenBionics, Open Hand Project) provide editable templates for 3D printing. Prototypes for haptic research often use the same fabrication methods, powered by the same open-source electronics platforms, like Arduino and Raspberry Pi. Modular, DIY electronics components and kits for wearable technology have promising overlaps with creating personalized haptic interfaces, allowing users to tailor the solution to their unique needs. Manufacturers have created custom boards and components for haptic applications [61]. However, this development technique still has a technical barrier to entry.

Crowdsourcing design is a promising method to overcome this barrier. Adjustable templates and modular components can enable the democratization of design, so individual solutions can be generated as iterations off of the original. These design features need to be intentional and customization perceivable by the users as intended by its creator.

4. Tactile user interfaces

Tactile user interfaces incorporate all of the above discussed qualities in haptic interface design. Tangible objects in which the physical configuration of the components intuitively map to the function of the object. They have high Affordance in their design simply because the physical and mechanistic nature of the object allow for limited options and limited interpretations of those options. We encounter tangible, tactile user interfaces everywhere (i.e., flipping a wall button to turn on the lights). The physical sensation of flipping a switch gives a first level of confirmation.

We commonly associate these tactile UIs with physical objects, with physical consequences and haptic feedback associated with their purpose. Even input devices with digital outputs like keyboards and mouse utilize haptic actuation to provide immediate feedback on the user's action. UI/UX design guidelines encourage GUI counterparts to reproduce haptic feedback. For example the vibrotactile feedback on the smartphone reproduces the sensation of a button press to provide confirmation that the input is received. However, as touch displays are now dominant due to their versatility, they also inherited the windows, icons, menus, and pointing device model. This approach leaves few options for haptic feedback to supplement the interaction, evident by the "Accessibility Modes" touch displays offer the blind. Voice-overs associated with point inputs force users with disabilities to adapt to the UI schema of our graphic conventions.

We are excited to see the dominance of the WIMP interaction model being challenged by novel UI devices. Designs of input systems specifically tailored to the context of the activity, in which the haptic feedback is an inherent quality of the interface rather than an accessory added after the fact. Colleague Viraj Joshi's collection of tactile user interface (TUI) designs showcase novel and intuitive input devices. Joshi's Beethoven TUI incorporates telescopic, rotational, and push-select motion into one device for navigating through tiers of data (**Figure 1**). Each degree of freedom maps intuitively to an axis of navigation through the breadth of dataset, whereas the conventional UI forces the user to interpret graphic layout to access tiered information.

We hope that the inclusion of TUI design exemplifies the intuitive benefits of haptic design, as well as the misconception that haptic feedback must be a transmutation of digital data. The haptic output can literally be a physical characteristic of the device itself.

Figure 1. Joshi's Beethoven TUI design, virajvjoshi.com.

5. Discussion

We argue that haptic interfaces when designed right have a significant advantage for the elderly, for whom visual and auditory processing can be overwhelming. Haptic interfaces have been applied in a wide range of contexts. Everyone with a smartphone has familiarity with it. As a result, the general understanding of its potential is shaped by the vibrotactile actuator in our smart devices. The development in other industries, notably the video-game industry, of multi-modal devices will steadily introduce the general public to novel haptic experiences. Complementary to the proliferation of virtual reality, haptic technology will enhance the activities VR already allow. However, the trend in Internet-of-Things and smart devices on the market show a lowered consideration for fail-safes in recent years. Cybersecurity breaches are rampant in smart devices. For products that help the disabled and elderly perform and survive, malfunctions or failures, intended or otherwise, can put the user in physical danger.

Assistive technology for the elderly conjures up expectations of advanced robotic automation solutions to help perform functions of a human. In reality, our interviews show that this is not necessary. Technological interventions for the elderly do not actually need to tackle complicated tasks. We spoke with elderly PACE patients and their caretakers, revealing that the most commonly requested help is interpreting information. Bills, medicine descriptions, product setups instructions, and the like, all of which are performed through video/audio calls. House-calls are scheduled and emergencies rare. One caretaker we spoke to notes that calls from patients stems partly from loneliness. Another caretaker remarks that most of the instructional interactions with patients are reminders and repeats of previously given instructions. Due to diminished cognitive function, patients routinely forget portions of how to perform a task and seek repeated guidance. In other cases, pride and desire to be independent often keeps patients from seeking help when necessary. In one instance, a female patient fell in her home but refused to activate her emergency alert device until hours later, when her own efforts were proven to be ineffective. These varying degrees of needs and different preferences make designing for the elderly difficult. But we need not complicated solutions. Instead, we need customizable tools and interfaces for each unique situation.

6. Conclusion and future work

Advancements in virtual reality technology catalyzes the development of haptic technology but do not exactly overlap with the needs of extreme and elderly users. Most of them deal with sensory and cognitive disabilities and deficiencies. Despite numerous advantages that the technology offer these people, they cannot make good use of the interfaces to access them. The most common outcome is sensory overload. This chapter outlined three desired characteristics to strive for when designing novel haptic interfaces: Immersion, Animacy, and Affordance. The goal of Immersion in this case is not more detailed simulations but more thoughtful ones, often simpler ones. Particularly for immersive experiences involving telepresence, the mediated touch need not be able to convey complex information. As previously stated, Animacy is produced simply from the presence of haptic stimulus rather than its actual content. We argue that long-term usage, rather than isolated instances of use, is the key to fostering connection. Stimuli provided organically over time informs the feeling of Animacy in the interaction.

Affordances in design of the interfaces for the elderly should seek to capture and communicate the crucial elements of the interaction while filtering out the rest, resulting in an artificial model within the informational processing capacity of the user. While neuroplasticity allows the brain to adapt to new interfaces, old age does come with a reduction in its ability to remap new information and action. Therefore, taking advantage of existing neurological phenomenon (haptic illusions), using metaphorical UI's, and/or combining with other modalities are promising ways to engage new users without training. If training is necessary, incorporating social learning opportunities is encouraged.

In information design, there is already pushback from the general public on the abundance of data we are exposed to in our day-to-day. Designed visual stimuli bombard us everywhere we are, primarily through displays that we own. Trends indicate a desire for more simplified and curated representations, less clutter in our visual field. In the future, we can expect haptic interfaces to be more prevalent in our activities, where more design leads to less information but refined presentation. This shift will be a boon to the rapidly aging population. We believe that this prediction holds in the long run, even as the generation with proficiency in computing esthetics and practices become elderly. Simply because by 2050, half of the population is expected to be nearsighted due to our computer obsessed lifestyle [62].

We hope to take this work further by creating a set of heuristics for the design of haptic interfaces, expand upon the three key qualities of Immersion, Animacy, and Affordance we distilled from a broad analysis of existing products and research prototypes. We will continue monitoring this design space and categorizing the emergent features to ideally create a taxonomy and design toolkit for haptic interfaces.

Author details

Eric Heng Gu

Address all correspondence to: heng.gu@network.rca.ac.uk

Ar+eliers Studio, Imperial College London, London, UK

References

[1] Holly Z. More than meets the eye: NASA scientists listen to data. NASA. 2 Sept. 2014. Available from: www.nasa.gov/content/goddard/more-than-meets-the-eye-nasa-scientists-listen-to-data/

[2] World Health Organization. Mental Health of Older Adults. World Health Organization. www.who.int/mediacentre/factsheets/fs381/en/

[3] Japan: Population by Age Group 2020 | Statistic. Statista. www.statista.com/statistics/612575/japan-population-age-group/

[4] Bach-Y-Rita P, Kercel SW. Sensory substitution and the human-machine interface. Trends in Cognitive Sciences. 2003;**7**(12):541-546. DOI: 10.1016/j.tics.2003.10.013

[5] Bai J et al. Smart guiding glasses for visually impaired people in indoor environment. IEEE Transactions on Consumer Electronics. 2017;**63**(3):258-266. DOI: 10.1109/tce.2017.014980

[6] Hudson HL et al. Implantable miniature telescope for the treatment of visual acuity loss resulting from end-stage age-related macular degeneration: 1-year results. Ophthalmology. 2006;**113**(11):1987-2001. DOI: 10.1016/j.ophtha.2006.07.010

[7] Heng G et al. Towards performance feedback through tactile displays to improve learning archery. In: Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers—UbiComp '15; 2015. DOI: 10.1145/2800835.2800893

[8] Azusa K et al. Casper. In: Proceedings of the 7th Augmented Human International Conference 2016 on—AH '16; 2016. DOI: 10.1145/2875194.2875197

[9] Kouta M et al. TECHTILE Toolkit. In: ACM SIGGRAPH 2012 Emerging Technologies on—SIGGRAPH '12; 2012. DOI: 10.1145/2343456.2343478

[10] Alais D, Burr D. The ventriloquist effect results from near-optimal bimodal integration. Current Biology. 2004;**14**(3):257-262. DOI: 10.1016/j.cub.2004.01.029

[11] Liu Y-C. Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced Traveller information systems. Ergonomics. 2001;**44**(4):425-442. DOI: 10.1080/00140130010011369

[12] Fernando B et al. Haptics: Perception, devices, control, and applications. In: 10th International Conference, EuroHaptics 2016, London, UK, July 4-7, 2016, Proceedings, Part II. Springer International Publishing; 2016

[13] Novich SD, Eagleman DM. Using space and time to encode vibrotactile information: Toward an estimate of the skin's achievable throughput. Experimental Brain Research. 2015;**233**(10):2777-2788. DOI: 10.1007/s00221-015-4346-1

[14] Iona CS. Finance and sensory addition: Feeling the system and perceiving the stock market. In: ASCA Workshop 2016, Transparent/Opacity; 2016

[15] Pedro L et al. Providing haptics to walls & heavy objects in virtual reality by means of electrical muscle stimulation. In: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems—CHI '17; 2017. DOI: 10.1145/3025453.3025600

[16] Haruto M et al. Walk-In Music. In: Adjunct Publication of the 30th Annual ACM Symposium on User Interface Software and Technology—UIST '17; 2017. DOI: 10.1145/3131785.3131822

[17] Seokhee J, Harders M. Extending haptic augmented reality: Modulating stiffness during two-point squeezing. In: 2012 IEEE Haptics Symposium (HAPTICS); 2012. DOI: 10.1109/haptic.2012.6183782

[18] Inrak C et al. CLAW: A multifunctional handheld haptic controller for grasping, touching, and triggering in virtual reality. CHI. 2018. ACM 978-1-4503-5620-6

[19] Hiroshi Y. Exiii has developed a 'touchable-CAD' 3D design review tool. Exiii Haptic Wearable Device for XR, 28 Feb. 2018, exiii.jp/2018/02/28/exiii-has-developed-a-touchable-cad-3d-design-review-tool/

[20] Jessica T et al. ForceForm. In: Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces—ITS '13; 2013. DOI: 10.1145/2512349.2512807

[21] Geldard FA, Sherrick CE. The cutaneous "rabbit": A perceptual illusion. Science. 1972; **178**(4057):178-179. DOI: 10.1126/science.178.4057.178. PMID: 5076909

[22] Sayaka O et al. /Ed (slashed). In: ACM SIGGRAPH 2008 New Tech Demos on - SIGGRAPH '08; 2008. DOI: 10.1145/1401615.1401629

[23] Yukari K et al. Synesthesia suit. In: ACM SIGGRAPH 2016 VR Village on—SIGGRAPH '16; 2016. DOI: 10.1145/2929490.2932629

[24] KOR-FX 4DFX Haptic Gaming Vest. In: KOR-FX 4DFX Haptic Gaming Vest. www.korfx.com/

[25] Ali I et al. Vr360Hd. In: Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology—VRST '16; 2016. DOI: 10.1145/2993369.2993404

[26] Wolfgang S. Tangible interfaces as a chance for higher technology acceptance by the elderly. In: Proceedings of the 12th International Conference on Computer Systems and Technologies—CompSysTech '11; 2011. DOI: 10.1145/2023607.2023660

[27] Massimi M, Baecker RM, Wu M. Using participatory activities with seniors to critique, build, and evaluate mobile phones. In: 9th International ACM SIGACCESS Conference on Computers and Accessibility, vol. 6185. 2007. pp. 155-162

[28] Rachel M. Remember second life? Its creators are back with a virtual reality platform. MIT Technology Review. 3 Feb. 2017. Available from: www.technologyreview.com/s/603422/second-life-is-back-for-a-third-life-this-time-in-virtual-reality/

[29] Creativity FIRST for Technology Innovator Dean Kamen. Creativity Comes First for Prolific Inventor Dean Kamen: SPIE Professional. Available from: spie.org/membership/spie-professional-magazine/spie-professional-archives-and-special-content/2011april-archive/creativity-first?SSO=1

[30] Mikhail L, Miguel N. Brain–machine interfaces: Past, present and future. Trends in Neurosciences, Elsevier Current Trends, 21 July 2006. Available from: www.sciencedirect.com/science/article/pii/S0166223606001470

[31] Park DC, Bischof GN. Neuroplasticity, aging, and cognitive function. In: Handbook of the Psychology of Aging. 2011. pp. 109-119. DOI: 10.1016/b978-0-12-380882-0.00007-3

[32] Tucker AM, Stern Y. Cognitive reserve in aging. ScienceOpen Research. 2011. DOI: 10.14293/s2199-1006.1.sor-socsci.adkhnx.v1

[33] Edelson, Stephen M, et al. Behavioral and physiological effects of deep pressure on children with autism: A pilot study evaluating the efficacy of Grandin's hug machine. American Journal of Occupational Therapy, American Occupational Therapy Association, 1 Mar. 1999, Available from: ajot.aota.org/article.aspx?articleid=1873405

[34] Darwin C. The Expression of the Emotions in Man and Animals. Wallachia; 2015

[35] Morrison I et al. The skin as a social organ. Experimental Brain Research. 2010;**204**(3):305-314. DOI: 10.1007/s00221-009-2007-y

[36] Edgar B et al. Using haptics to assist performers in making gestures to a musical instrument. NIME 2009

[37] Takahashi K et al. Haptics rendering and applications. Abstract Feelings Emerging from Haptic Stimulation. 2012. DOI: 10.5772/27906

[38] Huisman et al. Self Touch to Touch Others: Designing the Tactile Sleeve for Social Touch. Digital Academic Repository—University of Amsterdam, Barcelona Universitat Pompeu Fabra; 1 Jan. 1970. dare.uva.nl/personal/search?metis.record.id=392511

[39] Kanosue K. Encyclopedia of Temperature and Body. Asakura Publishing Co., Ltd; 2010. pp. 37-39

[40] Penfield S. Temperature perception and signal transduction in plants. New Phytlogist. 2007

[41] Azevedo RT et al. The calming effect of a new wearable device during the anticipation of public speech. Scientific Reports. 2017;**7**(1). DOI: 10.1038/s41598-017-02274-2

[42] Cheok AD. Huggy pajama: A remote interactive touch and hugging system. Art and Technology of Entertainment Computing and Communication. 2010;161-194. DOI: 10.1007/978-1-84996-137-0_7

[43] Blum JR, Cooperstock JR. Expressing human state via parameterized haptic feedback for mobile remote implicit communication. In: Proceedings of the 7th Augmented Human International Conference 2016 on—AH '16; 2016. DOI: 10.1145/2875194.2875225

[44] Julsaksrisakul P et al. Nene. In: Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers on—UbiComp '17; 2017. DOI: 10.1145/3123024.3123156

[45] Wada K et al. Effects of robot-assisted activity for elderly people and nurses at a day service center. In: Proceedings of the IEEE. 2004;92(11):1780-1788. DOI: 10.1109/jproc.2004.835378

[46] Ono T, Tomita Y, Inose M, Ota T, Kimura A, Liu M, Ushiba J. Multimodal sensory feedback associated with motor attempts alters BOLD responses to paralyzed hand movement in chronic stroke patients. Brain Topography. 2015;**28**:340-351

[47] Siklanyi CS. Virtual reality in healthcare. In: Intelligent Paradigms for Assistive and Preventive Healthcare Studies in Computational Intelligence. pp. 87-116. DOI: 10.1007/11418337_3

[48] Hatzfeld C. Haptics as an Interaction Modality." Springer: London, 1 Jan. 1970, Available from: link.springer.com/chapter/10.1007/978-1-4471-6518-7_2/fulltext.html

[49] Sanchez S et al. Embodied reading. In: Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems—CHI EA '16; 2016. DOI: 10.1145/2851581.2892353

[50] Spirkovska L. Summary of Tactile User Interfaces Techniques and Systems. NASA Ames Research Center; 2005

[51] Tsukada K, Yasumura M. ActiveBelt: Belt-type wearable tactile display for directional navigation. In: UbiComp 2004: Ubiquitous Computing Lecture Notes in Computer Science; 2004. pp. 384-399. DOI: 10.1007/978-3-540-30119-6_23

[52] Norman D. The Design of Everyday Things. Basic Books; 2013

[53] Baba Y et al. Collision avoidance by running insects: Antennal guidance in cockroaches. Journal of Experimental Biology. 2010;**213**(13):2294-2302. DOI: 10.1242/jeb.036996

[54] Cassinelli A et al. Haptic radar/extended skin project. In: ACM SIGGRAPH 2006 Sketches on—SIGGRAPH '06; 2006. DOI: 10.1145/1179849.1179892

[55] Qureshi A et al. The method of loci as a mnemonic device to facilitate learning in endocrinology leads to improvement in student performance as measured by assessments. Advances in Physiology Education. 2014;**38**(2):140-144. DOI: 10.1152/advan.00092.2013

[56] Gu H. Keepsake. Royal College of Art; 2016. Available from: www.rca.ac.uk/students/heng-gu/

[57] Barthel R et al. An internet of old things as an augmented memory system. Personal and Ubiquitous Computing. 2011;**17**(2):321-333. DOI: 10.1007/s00779-011-0496-8

[58] Fujisawa A et al. Acquisition of a mental strategy to control a virtual tail via brain-computer interface. Cognitive Neuroscience. 2018:1-14. DOI: 10.1080/17588928.2018.1426564

[59] Bond Touch. Facebook. Available from: www.facebook.com/pg/BondTouch/community/?ref=page_internal

[60] Nuwer R. Makers print out durable, custom prosthetic hands for needy kids. Popular Science. 26 Jan. 2015. Available from: www.popsci.com/lets-give-kids-3-d-printed-hand

[61] Einarson E. Go bionic with these wearable Arduino projects. Wired, Conde Nast; 2 Jan. 2013. Available from: www.wired.com/2013/01/wearable-arduinos/

[62] Beck J. In 2050, half the world will be nearsighted. The Atlantic. Atlantic Media Company; 19 Feb. 2016. Available from: www.theatlantic.com/health/archive/2016/02/in-2050-half-the-world-will-be-nearsighted/468606/