THE FUTURE OF HAPTICS
IN HEALTHCARE SIMULATION

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Introduction

Haptic technology, which enables touch sensation, holds significant potential in healthcare education and practice, especially when combined with extended realities such as virtual reality (VR) or augmented reality (AR). Sensations, such as force, touch, and temperature, demonstrate possibilities that haptic devices may be helpful to simulate clinical tasks such as feeling for a fever, palpating a vein, or other required psychomotor skills. This paper explores the historical development and emerging trends of haptic technology in healthcare simulation, analyzing the future potential for enhancing clinical education and practice.

The word haptic originates from the Greek word haptesthai, haptikos, meaning to touch (Carter et al., 2013; Merriam-Webster, n.d). The SSH dictionary defines *haptics* as "devices that provide tactile feedback to the user." The sense of touch and feelings of sensation are more complex than just one sensory mechanism. Haptic technology sends forces, vibrations, and motions to the user through the somatosensory system to engage the user and elicit a sensation.

The history of haptics is elusive and may have originated in ancient times, but it includes concepts integral to human experiences. Early studies of touch and sensory perception, led by Ernst Heinrich Weber, laid the foundational groundwork for sensory thresholds and informed the basis of experiential psychology (Grunwald, 2008). Further advancements in the early 1960s, including Ralph Mosher's development of the "handyman" robotic arm exoskeleton, created the foundation for modern robotic surgery systems like the Da Vinci (Mosher, 1964; Hugues, 2000). Healthcare is not the only industry that has found haptics advantageous.

The entertainment industry has used haptics as far back as 1959's Castle Horror film "The Tingler," which used a device installed in theater seats called "Percepto!" to shake seats in time with the action on the screen. In 1976, Sega brought similar haptics into the arcade gaming industry by creating a rumble seat for its motocross game. By the late 1980s and early 1990s, haptics, especially vibrotactile feedback, were widespread in gaming industry controllers in both the arcade setting and the rapidly growing home console market, where they started as an optional accessory and were later incorporated directly into the controllers. This technology has transferred, along with the analog joystick, into the VR hand controllers for most commercial VR headsets and, therefore, is the most ubiquitous form of haptics available to commodity VR installations. Domestication of haptics has been successful in multiple industries, including Healthcare, Aviation, Space Exploration, Automotive, and Personal Performance (sports). Today, haptic effects are included in personal computing devices such as smartphones and smartwatches to alert users of new messages and health trends and enable safety features such as calling emergency services after a fall. The technology is growing and continuing to improve for end users.

Applying haptics across these specific examples suggests an additive or enrichment to the overall user experience. These examples represent haptic domestication in that they are near-imperceptible to the user as a haptic-specific sensation but rather a kinesthetic layer of the overarching whole. Haptic sensations, coupled with specific audio and visual cues of our mobile devices, vehicle dashboards, or wearable devices, convey a particular alert, meaning, or message. This holistic kinesthetic experience is no longer superlative in these everyday realms but rather an expectation for the modern technological interface that will become more commonplace over time (Parisi, 2019). A similar domestication of healthcare haptics will occur in the coming years with technological advances that make touch a central part of patient care and healthcare professional education.

One of the primary challenges to haptics has been the dearth of a unified history, theory, or codified terminology for understanding, assessing, and categorizing haptic sensations and their implications (Parisi, 2019). Definitional imprecision in this arena has stagnated scholarship, which impedes research outcomes demonstrating haptics' efficacy in creating or reinforcing meaning within audiovisual media to enhance immersion, understanding, and knowledge retention. An increase in quantitative and qualitative studies can be gained with the maturation of a shared scientific vocabulary and matrix for understanding haptic sensations, which will not only create further impetus for industry research and development efforts but allow content creators who author these experiences for hardware and software solutions to harness the effective implementation of haptics within particular audiovisual platforms.

There are frameworks by which one can divide haptic feedback into categories, such as the underlying technology used to create the sensations or the form factor the technology uses. However, the most helpful taxonomy for this paper is to divide them by the type of sensations they can create. The sensations can be categorized into Texture, Pressure, Force, Thermal, Electromagnetic, Ultrasonic, and “Other.” Within these categories, there can be further breakdown of the technologies by their form factor and how they can be integrated into other systems. **See Table 1.**

Definitions

Haptics is not only a science; it is an art. Unlike other senses, which generally only detect one kind of stimulus (e.g., vision detects light), the “touch” sense is actually a collection of different senses, each of which uses different nerve pathways but is perceived as one (Gallace & Spence, 2014; Roudaut et al., 2012). The collection of senses includes thermal, kinesthetic, pain, itching, light touch, deep touch, and discriminative touch, and is tied to other forms of sensory feedback such as proprioception and the vestibular system, which, in combination, allows sense of the world around us, and our place in it. There are differing opinions on which of these senses must be simulated to create realistic simulations.

Most dictionary definitions do not differentiate between *haptics* and *tactile* sensations. However, researchers and developers use haptics to include sensations in two parts: touch and kinesthesis, and tactile stimulation of the skin is limited to mechanical stimulation (ISO, 2011). Tactile, relating to or being the sense of touch, can further be broken down into two categories: spatial and non-spatial. Spatial haptics, including texture, pressure, thermal, electromagnetic, and ultrasonic, can be categorized as contact vs. non-contact. **See Figure 1.**

Haptic devices and feedback systems typically rely on specialized software and application programming interfaces (APIs) that are not commonly included in standard equipment. As a result, developers mining to integrate haptics into simulations must manually incorporate these tools, which presents a significant challenge for widespread adoption. Understanding the definitions and possibilities of haptic feedback allows healthcare educators and practice entities to choose devices that will best support their learning needs.

Touch Senses

1. Touch - The detection of a mechanical stimulus impacting the skin, including innocuous and noxious mechanical stimuli (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; The Stanford Encyclopedia of Philosophy, 2024).

2. Light Touch - The detection of light touches on the skin, a very responsive system designed to allow us to react to unexpected stimuli very quickly (e.g., touch a spiderweb) (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; The Stanford Encyclopedia of Philosophy, 2024).

3. Deep Touch - The sense of pressure detected in the deeper layers of the skin (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; The Stanford Encyclopedia of Philosophy, 2024).

4. Discriminative Touch - A combination of stretch sensors, light touch sensors, and temperature sensors that give a qualitative sense of “what” is being touched (e.g.

that was sticky) (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; The Stanford Encyclopedia of Philosophy, 2024).

5. Kinesthesis - the ability to feel movements of the limbs and body based on the activity of the muscles, tendons, and joints. (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; The Stanford Encyclopedia of Philosophy, 2024).

6. Vestibular - relating to the sense of equilibrium, like detected in the inner ear. (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; The Stanford Encyclopedia of Philosophy, 2024).

7. Proprioception - the ability to sense the position and location and orientation and movement of the body and its parts (includes Kinesthesis as well as spatial sense) (Griffin Occupational Therapy, 2018; Roudaut et al., 2012; The Stanford Encyclopedia of Philosophy, 2024).

Haptic Stimulation Techniques

1. Texture - Ability to simulate various sensations on the fingertips and/or hands to simulate the sensations of surface texture. Texture sensations are used to enhance virtual objects, interactions, and environments (Hayward & Astley, 2016).

2. Force—The ability to simulate the solidity of objects by preventing the fingers and/or hands/tools from moving through the space that would be occupied by a solid object; the ability to simulate soft and semi-rigid pliability. Force Feedback replicates the resistance or force exerted by objects, allowing users to feel weight or resistance, which is crucial for tasks requiring precision or specific grip strength (Zhu et al., 2021).

3. Thermal - The ability to simulate hot or cold sensations on various body parts and use temperature contrast to simulate extreme heat or cold. Thermal feedback simulates temperature changes, allowing users to feel heat or cold sensations, which can be important for diagnosing conditions like fever.

4. Electromagnetic - Ability to create a virtual magnetic field, usually used in haptic suits or gloves, to create the sensation of touch or the sensation of being up against an object. Electromagnetic administers either an electric or magnetic pulse to stimulate the skin, ultimately to the nerves giving feedback to the user.

5. Ultrasonics - use high-frequency sound waves which exert pressure on the skin to create sensations. Hand tracking in virtual reality is an example of this (Carter, et al., 2013).

Other—This category is a catch-all for touch sensations that do not fit the above categories and includes electroshock and low-frequency sound inducers, as well as other technologies.

Non-spatial

Non-spatial haptics do not rely on physical movement or position and include vibration. This is the most common, studied, and widespread tactile haptic.

1. Vibrotactile feedback stimulates the sensation of touch by creating pressure and vibrations on the skin (ISO, 2011).

Current State

Currently, various haptic devices are limitedly employed in simulation training to deliver touch sensations. Around 70 percent of survey respondents stated they deployed at least one type of haptic device. These devices often include immersive controllers, haptic gloves, haptic pens, wearables, or exoskeletons integrated into simulators for a specific task (i.e., lumbar puncture, laparoscopic surgery), or medical tools that have incorporated trackers.

Interestingly, survey participants recognized that healthcare tools integrated into digital display devices, such as ultrasound probes and laryngoscopes, are the most commonly used haptic technologies (43.3%). This indicates there might be some ambiguity surrounding the term "haptics." Following this, virtual reality (VR) immersive controllers accounted for 36.7%, and wearable devices for standardized patients made up 30%. Despite the adoption of these devices, thirty percent of programs do not utilize any haptic technologies. Applications of the devices are primarily used for airway management, surgical skills training, and invasive procedures, such as central line insertion and robotic surgery. Incorporating trackers into the actual tool used in a healthcare task (i.e., laryngoscope, bag valve mask) can also provide haptic feedback in a simulator that is realistic to the feel of performing the task. This shows a clear focus on technical skills alone.

Several barriers impede the broader adoption and optimal use of haptic systems in healthcare simulation. The survey finds that financial constraints are the most significant challenge (66.7%), followed by the lack of appropriate content, curriculum, and simulation experiences (43.3%). A participant noted, *"Access to quality haptic feedback needs to improve."* Faculty-related issues such as time limitations and inadequate training (36.78%) also play a crucial role in hindering the integration of haptics into these technologies. Technological limitations are a significant concern for 33.3 percent of respondents, highlighting the need for continued innovation in this space. Other challenges include the shortage of support staff (23.3%) and infrastructure constraints, which may impact the scalability of haptics in healthcare simulation programs.

Despite these hurdles, there is a growing recognition of the value of haptics in healthcare simulation technology. The majority of survey participants (60%) regard haptics as moderately or very important, with a small but notable group (10%) believe that haptic technology is not important in healthcare simulation. However, the quality of current haptic technologies is rated as moderate by the majority of respondents (53.3%), with notable skepticism about the overall capability of the existing systems to deliver high-quality performance or evaluation. One respondent noted, *"Unless you are a training surgeon, haptic technologies are not that useful."* While haptics technology is seen as functional, they are also not yet seen as revolutionary, and there is an implicit expectation for ongoing improvements.

Problems with Technology

A review of existing literature indicates that haptic devices offer different types of feedback, including tactile, thermal, force, or a combination (Zhu et al., 2024). Each type of feedback presents unique challenges. Common issues across all types of devices include high costs, bulkiness, movement interference, high power consumption, and difficulty accommodating different users. Tactile feedback, specifically, is challenging to provide complete hand coverage to meet the needs of every user. Force feedback faces difficulties balancing active force mechanisms and lighter, passive actuators. Emerging technologies, such as liquid metal, transcutaneous nerve stimulation, and air pressure systems, are being developed to enhance haptic feedback quality. Many respondents of the survey acknowledged technology immaturity and limitations, with concerns regarding cost-effectiveness and limited sophistication of these devices further contributing to this suspicion. The survey also showed variability in perceived utility, with surgical application viewed as the most promising.

Although these advancements show promise, current haptic devices have limitations that need to be addressed before effective integration into training and education programs is possible. The ideal haptic device would be lightweight, affordable, user-friendly, and capable of delivering multiple types of sensory feedback that can be utilized across healthcare tasks. Furthermore, assessing the efficacy of different haptic feedback and devices remains challenging.

Evidence of Efficacy

Evaluating the efficacy of haptic devices for healthcare simulation remains challenging. Survey result respondents emphasize the need for expert evaluation for validation and rigor in simulation modalities that utilize haptic technologies. As stated previously, definitions of haptic devices in training environments vary widely. Haptic devices have been defined based on their form, user interaction or wearability, and underlying technology. Adilkhanov et al. (2022) conducted a literature review that analyzed over 90 haptic devices and subsequently created a taxonomy of haptic devices based on the extent of wearability. They defined broad categories of devices as: 1). Grounded (e.g., haptic pens), 2). Hand-held (e.g., video game controllers), or 3). Wearable (e.g., haptic gloves, exoskeletons). This differs from other reviews of haptic devices that focus on the types of techniques for providing haptic feedback, such as actuator type (Leleve et al., 2020). For example, haptic devices may use brakes, which are passive actuators that can provide a feeling of force feedback that stops a user's hand from moving, simulating a solid object. This differs from pneumatic actuators that may use compressed air to create the feeling of force. These haptic devices provide a feeling of force feedback to indicate touching a solid object. The underlying technology differs, offering benefits and limitations for implementation into healthcare simulation.

An additional issue with assessing the efficacy of haptic devices in healthcare simulation is the low quality of the evidence. The research is in the gaming industry and is limited to the healthcare industry. At the same time, the topics of training are highly variable. Haptic devices have been used in healthcare simulation for disparate tasks, including suturing, endoscopy, laparoscopy, palpation, ultrasound, and in diverse specialties such as dentistry, emergency medicine, gynecology, and surgery (Coles et al., 2010; Escobar-Castillejos et al., 2016). Although many examples of haptics are used in healthcare training, most reviews on the efficacy of haptics in healthcare simulation have focused on surgical simulations (Azher et al., 2024; Mackenzie et al., 2022). The results of these literature reviews highlighted the lack of quality evidence to support conclusions on the impact of haptics in healthcare training due to small sample sizes, biased study designs, incomplete reporting practices, and a dearth of evidence on the transfer of training to clinical practice or patient outcomes. The notable conclusions from these reviews and surveys are that there is an urgent need to standardize research protocols, incorporate larger sample sizes, validate simulators and simulation methods in various contexts and for different learners, and ultimately measure patient outcomes.

New methods of creating and integrating sensors and actuators, along with innovative feedback strategies, are necessary to address these limitations. Further research is also essential to understand how and when to best use haptic devices in healthcare simulation, particularly to integrate multiple feedback types or incorporate artificial intelligence. Haptic devices present the potential for enhancing the sensation of touch during healthcare training, but several technical and practical challenges must be resolved. The call for the collaborative development of open-source haptic preprogramming underscores the importance of ongoing research and development which are crucial to realize the full potential of the technology in healthcare education.

Future State

Prominent manifestations of haptics in healthcare education are considered immersion-enhancing elements within Augmented Reality (AR) / Virtual Reality (VR) platforms. Haptics further the users' suspension of disbelief to deepen their connection to the teaching content through added immersion, which generates increased agency, empathy, understanding, and a heightened sense of involvement. Learning outcomes are amplified, and retention is improved with increased immersion (Zhang, et. al., 2019). The haptic sensorial layer is so synonymous with immersive environments across gaming, training, and all virtual world interactions that experiences without haptic properties feel inadequate or low-fidelity (Söderström et al., 2022). Thus, as AR/VR hardware and software proliferate in terms of accessibility and fidelity, complimentary haptic technologies will co-evolve to achieve similar breadth and depth of touch experiences in healthcare education.

Following a similar trajectory of haptic integration into personal everyday technologies (phones, wearables, vehicles, etc.), healthcare training will domesticate the haptic vocabulary within immersive environments. The additive immersion achieved through adding haptics in addition to a primarily audio-visual medium will become the expectation. Just as gamers have come to expect touch as a central component for increasing their connection to the virtual world, mobile phone users cannot fathom a mobile device without vibration, and automobile drivers rely on the gentle vibrations from one side of their seat to denote a vehicle is in their blind spot; health care practitioners will increasingly demand haptics are similarly integrated into the overarching kinesthetic experience.

One major challenge to the advancement of haptic adoption is the scientific validity of immersion that this additional layer of user experience adds. Hardware and development for AR/VR is extremely time- and cost-intensive, requiring exorbitant budgets and multi-year development cycles to launch head-mounted displays (HMD) and controller platforms that are iterations of previous models. Likewise, AR/VR software development involves an incredible investment of time and energy that must be justified through a valid return on investment. In lieu of compelling evidence that haptic layers of touch increase the impact, quality, and efficacy of an AR/VR experience that sufficiently offsets the investment, there is a perpetual “chicken and egg” dilemma in the haptic arena. Without a shared, universal language for understanding haptic experiences and research to illustrate its impact, healthcare haptic technology will not achieve significant industry penetration in training or patient care.

Research indicates results, results designate impact, and impact stipulates investment. Haptic research is growing, as noted by the increase in scholarly publications from 250 in 1995, 4,500 in 2015, 7,200 in 2018, and over 230,000 in 2024 (Parisi, 2019; Google Scholar, 2024). Thus, a growing body of research around haptics in healthcare training and patient care outcomes will eventually yield results in terms of applications that create the best outcomes, which will further technology investment, will enrich the canvas of possibilities for haptic content creation, analysis, understanding, and implementation. As haptics become integrated into the healthcare experience for patients and practitioners, the common paradigm for interaction and user expectation will match that of the audiovisual realm. AR and VR platforms will standardize the haptic realm of possibility for enhanced immersion, which will further refine content creators' tool sets and processes for meaningful integration. Additionally, patient populations will increasingly expect haptic integration as they have come to expect from other personal technologies.

As an audio-visual-based platform enabled through telecommunications, telemedicine is a massively growing healthcare industry segment. Estimates suggest growth will continue, with the market expected to expand by 12% annually by 2026. This suggests a massive opportunity for research and industry to drive outcomes through the integration of touch and haptics into the telemedicine process for improved results. Palpating a patient’s abdomen or conducting neurological exams involving touch sensations via telemedicine are among the primary interests in the coming years (Khan, 2024). Integrating the haptic sensorial layer for both patients and providers will increase the efficacy of telemedicine for diagnostics and at-home patient care, further enabling cost savings for the healthcare industry at large.   Integrating haptic feedback into telemedicine consultations enhances clinical outcomes (Khan, 2024).

Prosthetics are another area where haptics can improve outcomes. A 2021 study on prosthetic-haptic integration found that upper-body prosthetics with haptic feedback required significantly less mental effort to operate than standard prosthetics. Haptic feedback in prosthetics enhances cognitive and task performance for users, suggesting possible expansion into prosthetic usability, monitoring, and care, which is a major hurdle to the successful integration of prosthetics into patients' daily lives (Khan, 2024).

While the breadth and depth of its adoption across healthcare has been deliberately paced, the haptic market has a substantial presence in the overarching technology field, valued at $3.44 Billion in 2023. The sector's growth is expected to continue, with projections that the industry will reach $6.96 billion by 2032 (SNS Insider, 2024). This annual growth rate of 7.26% from 2024 through 2032 demonstrates a strong appetite among haptic experience creators and users for adoption. While the nature of hardware and software solutions that will ultimately emerge by 2032 is undefined at this point in time, quantitative trends demonstrate the imminent integration of haptic technology adoption in healthcare and beyond, driven by a confluence of consumer demand and technological developments.

Conclusion

In conclusion, while haptic technology has the potential to revolutionize healthcare simulation, current limitations must be addressed to facilitate broader adoption. The use of standardized terminology and definitions to support industry, research, and innovation will ensure that the haptic technology can collaborate with other AR/VR, and audio-visual groups. Equally important is the development of unified standards for haptics between healthcare and industry to achieve interoperability across platforms and enhance the accessibility to content creation. Healthcare simulation professionals need to standardize terminology and frameworks to successfully integrate haptics. The future of haptics lies in overcoming these obstacles through the continued advancement of hardware, software, and interface design, which will lead to more immersive, adaptable, and effective educational tools. Further research is essential to address current challenges and fully harness haptics to meet the complex evolving needs of healthcare education.

Figure 1. Haptic Sensations

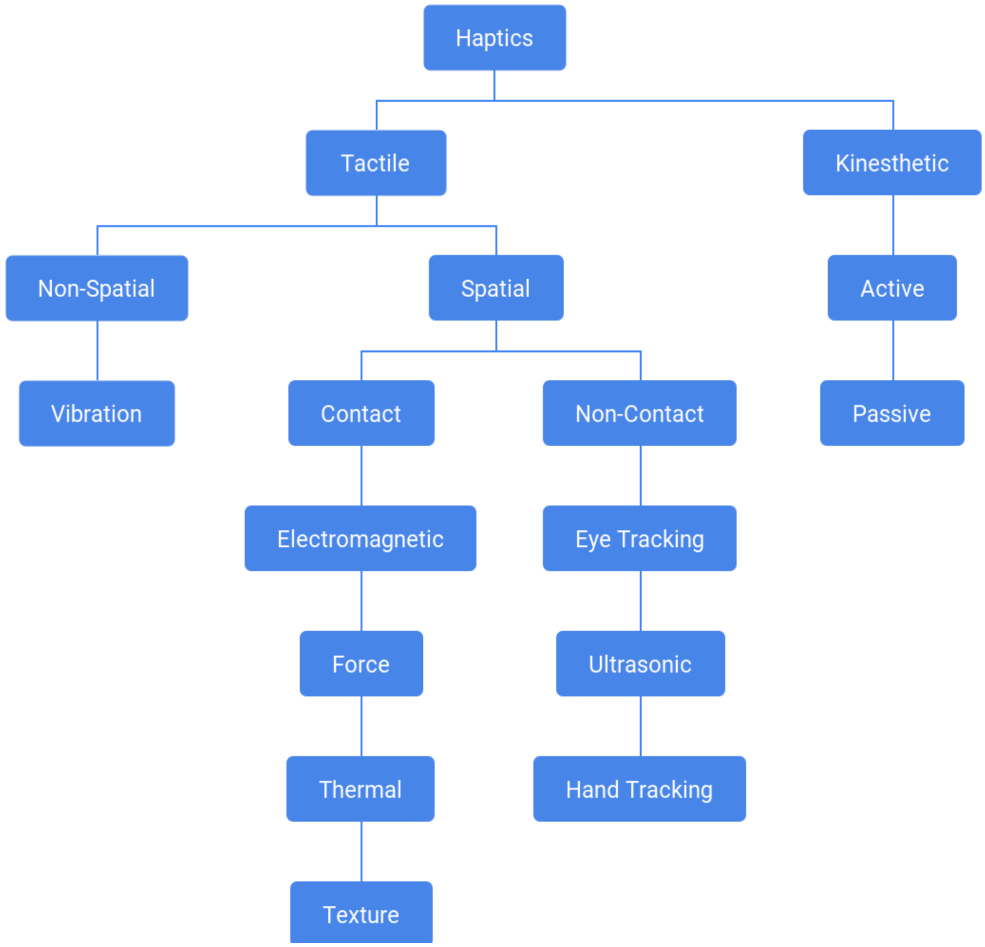

Table 1. Taxonomy of Haptic Feedback

Product	Image	Texture	Force	Thermal	Other	Notes
Vibrotactile Controllers		Y	N	N	N	Easy to integrate because it is part of the existing controller
Haptic Gloves		Y	Y	Y*	N	Haptic Gloves have various levels of feedback from simple fingertip sensations to full force-feedback on finger movement *Thermal capabilities may be available, but are not common
[UltraHaptics]()		Y	N	N	N	Can create texture in the air at a distance
Haptic Pens		Y	Y	N	N	Form factor restricts its range of operation
Exoskeleton		N	Y	N	N	Can provide resistance or assistance to simulate real-world forces

Hand Exoskeleton		N	Y	N	N	
Integrated Haptics (RASD)		Y	Y	N	N	Incorporating trackers into the actual tool used in a healthcare task (i.e., laryngoscope, bag valve mask) can also provide haptic feedback in a simulator that is realistic to the haptic feel of performing the task.

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