Building Haptic Systems with 3C's: Communication, Collaboration, and Confirmation

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

The completed studies presented in the subsequent chapters are the result of collaborative work between me and my research colleagues. The following notes provide some indication for the amount of their involvement:

1. Chapter 3 presents the Feel-Play-Imagine (FPI) process, for which workshop data were collected with the active participation of the Digital Oral Histories for Reconciliation team: Dr. Kristina Llewellyn, Dr. Jennifer Roberts-Smith and Dr. Jennifer Llewellyn, and former residents of Nova Scotia Home for Coloured Children: Tony Smith, Tracy Dorrington-Skinner and Gerry Morrison. Graduate student Ana Lucia Díaz de León Derby contributed to design discussions and assisted with data analysis, while Prof. Oliver Schneider supervised the project and advised on writing and concept development. Fiona Yang assisted with photography and contributed in the discussions.
   Paper: Bibhushan Raj Joshi, Ana Lucia Díaz de León Derby, Jennifer Llewellyn, Kristina Llewellyn, Jennifer Roberts-Smith, Oliver Schneider - Feel-Play-Imagine: Structured Introduction and Imagination of Haptics with Storytellers [second-round revision at IJHCS]

2. Chapter 3 and Part 2 of Chapter 4 uses the Tickle-Trunk toolkit. The hardware and firmware were designed and fabricated primarily by graduate student Ana Lucia Díaz de León Derby after a series of joint design meetings with the FPI team. Ana is the lead author of a paper titled "Tickle Trunk: A Toolkit for Playful Exploration and Brainstorming with Diverse Physical Interactions" that focuses exclusively on Tickle-Trunk, and the project forms the core contribution of her Master's thesis.
   Paper: Ana Lucia Díaz de León Derby, Faduma Ahmed, Bibhushan Raj Joshi, Kristina Llewellyn, Jennifer Roberts-Smith, Jennifer Llewellyn, Oliver Schneider - Tickle Trunk: A Toolkit for Playful Exploration and Brainstorming with Diverse Physical Interactions [in preparation for submission to TEI]

3. Chapter 4 introduces the Sankofa prototype. An early prototype was created with support from Chris Wang, and refinement of the initial 3D model for the final version was carried out by Ludwig W. Wall. The final Sankofa design bird-call vibrotactile module, electronics integration, and Unity module development were completed by Punit Kunjam under the supervision of Profs. Oliver Schneider and Michael Barnett-Cowan, in consultation with the DOHR team (Jennifer Llewellyn, Kristina Llewellyn, and Jennifer Roberts-Smith). Prof. Oliver Schneider supervised the project and advised on writing and concept development.

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4. Chapter 5 presents a scoping review of empirical studies that evaluate haptic devices. Data extraction and coding were carried out with the help of Alessandra Luz, Anchit Mishra, Khushi Savla, Chris Wang, and Faduma Ahmed. Tor-Salve Dalsgaard, Khushbu Shah, and Michael Xu contributed to title-and-abstract screening, while Sahand Ajami took part in both title-and-abstract screening and full-text screening. Prof. Oliver Schneider supervised the project and advised on writing and concept development.
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Abstract

Haptic technology is essential for bringing the sense of touch to digital and virtual environments, with applications ranging from accessibility to education and entertainment. However, the development of haptic systems is hindered by the absence of a standardized, human-centered process. This fragmentation leads to redundant efforts, and challenges in translating prototypes into reliable, user-ready products. This thesis addresses this gap by systematically investigating the haptic development lifecycle and introducing the 3C Guidelines, an integrated, evidence-based approach centered on three critical actions: Communication, Collaboration, and Confirmation.

To address the challenges in Communication, this research introduces and evaluates the Feel-Play-Imagine (FPI) process. Through a co-design workshop and a qualitative study with domain experts, the FPI process facilitates the communication of haptics projects through hands-on exploration to build a shared sensory literacy, and enabling stakeholders to effectively articulate and incorporate haptic concepts into their designs.

For Collaboration, this thesis presents findings from two distinct contexts: a four-year longitudinal case study on the co-design of an interface for a sensitive, community-driven narrative, and a participatory design workshop with haptics experts. Together, these studies revealed the critical importance of building restorative justice principles that fosters trust, synchronizes diverse work rhythms, and establishes shared ethical commitments, highlighting practices that support effective and inclusive teamwork in interdisciplinary haptic projects.

Finally, to understand Confirmation, this work includes a scoping review of 464 empirical studies, which mapped current evaluation practices in haptics research. The review identified significant gaps, including a reliance on ad-hoc metrics, a lack of demographic diversity in participant samples, and insufficient transparency in documentation. In response, this chapter provides a set of evidence-based recommendations to guide researchers toward more rigorous and reproducible evaluation methods.

By synthesizing the findings from these three investigations, this dissertation contributes a practical and actionable guideline designed to assist both novice and experienced practitioners in developing haptic systems more effectively. The 3C Guidelines provides structured yet flexible lens to improve how teams communicate, collaborate, and confirm their work, ultimately aiming to raise the quality, impact, and reproducibility of future haptic systems.

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Chapter 1

Introduction

Touch is one of the first senses to develop in the womb [75]. Harnessing this fundamental channel for digital interaction has been shown to affect learning outcomes, mediate social touch, support affective communication, and increase engagement in media contexts [242, 324, 467]. However, designing robust haptic systems - which tightly integrate hardware, firmware, software, and user-experience (UX) design - remains a significant technical challenge. Existing frameworks from fields such as interaction design provide guidance, but they are typically overly focused on graphical user interfaces - for instance, interaction design guidelines often emphasize visual aspects like visibility of system status rather than tactile considerations. Unlike visual and auditory systems, haptics lacks a broadly adopted, standardized development framework. Knowledge in this field is fragmented across laboratories, proprietary platforms, and informal practitioner expertise. Teams frequently reinvent fundamental processes, such as tactile rendering algorithms, usability evaluation methods, and core hardware designs (e.g., wearable gloves or other haptic interfaces); en-

counter preventable design errors, including inappropriate actuator or hardware choices, latency issues, poor ergonomic considerations, lack of consultation with domain experts, inadequate team composition, and flawed evaluation approaches; and face difficulties scaling prototypes into reliable, user-ready products. Consequently, translation to deployed user-facing systems remains limited.

This thesis addresses these issues by examining haptic system development through three critical actions: *Communication*, *Collaboration*, and *Confirmation*, collectively referred to as the "3 C's", positioned here as an *early-stage* design guideline. By synthesizing insights from research papers, workshops, and systematic literature reviews, I derive evidence-informed, early-stage guidelines for both novice and experienced haptic practitioners. These guidelines also provide structured support for non-haptician stakeholders—such as educators, clinicians, and designers—who are increasingly adopting and integrating haptic technologies into their professional practice.

1.1 Why a Development Framework Matters

In designing interactive systems, a product's success hinges not only on technical innovation, but also on adopting human-centered design principles, including an early and continuous focus on users, iterative refinement based on empirical measurement, and systematic usability evaluations [198]. Research in Human Computer Interaction (HCI) has shown that structured, user-centered methodologies—those that integrate user needs, iterative refinement, and empirical evaluation—lead to solutions that are both more usable and more robust in practice [82, 174]. A structured development cycle – encompassing

thorough requirements analysis, iterative prototyping, careful hardware and software integration, and rigorous validation – is vital for delivering haptic or interactive systems that meet their specifications and perform reliably in real-world use [280]. Crucially, this cycle must also accommodate change: as feedback or new constraints emerge, the design must evolve through flexible, iterative adjustments [410]. Such structured yet adaptive processes provide a roadmap that keeps interdisciplinary teams aligned around shared objectives and user expectations. In this thesis, the 3C is explicitly framed as an *early-stage* guideline that structures ideation, prototyping, and initial evaluation.

Contemporary HCI and design practices emphasize iteration, user involvement, and collaboration over rigid, sequential workflows. Instead of treating design and engineering as isolated phases, modern best practices encourage continuous loops of ideation, evaluation, and improvement that involve all stakeholders [82]. Participatory design methods, for example, invite users and domain experts to co-create from the start, ensuring that their perspectives shape the product throughout its development [171]. Iterative prototyping—constructing and refining successive design versions—enables teams to test hypotheses, catch usability issues early, and improve interaction quality over time. Moreover, adopting an iterative, human-centered approach aligns closely with principles of universal design and accessibility, embodied in the phrase 'nothing about us without us' - ensuring that users actively shape system evolution [118], thereby empowering them with greater agency and control over technologies they use. By continually integrating user input and expert insight, teams reduce the risk of late-stage surprises and converge on solutions that are both technically viable and experientially satisfying.

Interdisciplinary collaboration is also essential. Haptic systems span multiple technical

domains and design perspectives—requiring coordination across hardware, software, user experience, and human factors. Tools such as TactJam [581] support this coordination by giving collaborators a shared workspace for specifying vibrotactile cues, while tangible kits like Shape-Kit[619] let engineers and designers jointly prototype on-body form factors. Studies of haptic development practice reveal that effective outcomes depend on the shared efforts of diverse team members, not lone experts [566, 482]. Without a shared framework, disconnected work across roles can lead to miscommunication, redundant effort, and poorly integrated results. Conversely, structured collaboration promotes alignment and ensures that perceptual, functional, and experiential requirements are met in parallel [495]. Human-centered frameworks, such as User-Centered Design and Participatory Design encourage open communication, clarify expectations, and allow interdisciplinary teams to iterate effectively toward common goals. These principles are especially critical in haptics, which involves uniquely complex integration challenges:

Technological challenges include:

- Hardware engineering: selecting appropriate actuators, designing efficient driver electronics, and managing mechanical constraints.
- Firmware / software rendering: implementing precise timing control, closed-loop feedback, and generating perceptually meaningful waveforms.
- Human factors usability: accommodating perceptual thresholds, comfort, safety, and user performance [495].
- Experience design: translating abstract interaction goals (e.g., urgency, reassurance) into compelling haptic expressions and affective responses [37].

Team Level Challenges [482]

- Cross-disciplinary coordination: aligning mechanical, electrical, software, and UX specialists around a shared vocabulary and workflow (supported by an *early-stage* 3C guideline where appropriate).
- Knowledge transfer: making tacit haptic know-how explicit so that new team members and external partners can contribute effectively.

Societal and Cultural Challenges [482]

- Public perception and adoption: communicating use cases and evidence of benefit to end-users, clients, and other stakeholders.
- Ethical, accessibility, and cultural considerations: ensuring that haptic feedback respects diverse bodies, contexts, and norms.

Each of these domains has its own tools, terminology, and development steps. Without a unified process, teams risk misalignment—for instance, when a finalized hardware configuration limits the fidelity of an intended tactile effect, or when user testing is delayed until integration, leaving no room for course correction. Furthermore, haptics knowledge remains scattered across academic subfields, informal communities, and proprietary platforms [348, 205]. Practitioners often rely on trial-and-error, improvising workflows without consistent guidance. In this context, an *early-stage* development guideline such as 3C provides much-needed structure. It synchronizes efforts, makes assumptions testable, and minimizes preventable design pivots. Empirical work on haptic experience design confirms

that when teams lack shared processes, perceptual misfires and late-stage rework are common—even when technical specifications are met [284].

This absence of a unified process is particularly evident in the critical area of Confirmation, or evaluation. In HCI, evaluation methods are highly developed, with established instruments like the System Usability Scale (SUS) [81] and the ISO 9241 series of standards [393] providing widely accepted criteria. By contrast, haptic evaluation methods remain fragmented and lack unified standards [**?**]. As Fazlollahi et al. [161] observe, technical specifications often fail to capture performance quality in a consistent or meaningful way. While recent efforts like the Haptify benchmarking system [**?**] and the validated Haptic Experience Inventory (HXI) questionnaire [500] mark encouraging steps, they are not yet widely adopted. Consequently, most haptics studies still rely on ad-hoc tests, small-scale user trials, and unvalidated subjective reports, making results difficult to compare or reproduce [161, 482]. In this thesis, the 3C's Confirmation strand is scoped to *early-stage* practice, emphasizing consistent reporting fields and study design transparency rather than proposing a universal benchmark. This fragmentation is evident across the field; from electrotactile feedback to assistive technologies, researchers lack the standardized evaluation protocols needed to build a cumulative and rigorous evidence base [589, 259].

In summary, early-stage guidelines grounded in HCI give haptic teams a systematic way to communicate, collaborate, and validate initial design decisions. Such guidelines bring coherence to fragmented workflows, support traceable iteration, and help translate lessons into reproducible practices, enabling newcomers and experts to produce well-specified, accessible, and empirically grounded tactile systems.

1.2 Research Context

This section positions the thesis within the broader landscape of haptic research and practice. It first identifies the practitioners who drive haptic innovation - experts, novices, and domain specialists, and then surveys the typical stages and methodologies that shape a modern haptic project. Where relevant, we foreground an *early-stage* 3C guideline (Communication, Collaboration, Confirmation) to structure ideation, prototyping, and initial evaluation.

1.2.1 Who Are the Hapticians?

Borrowing from Schneider et al. [482], I define:

- **Expert hapticians**: seasoned researchers and engineers with end-to-end project expertise.
- **Novice hapticians**: early-career practitioners building their first or second haptic artefact.
- **Non-hapticians**: Domain experts, such as storytellers, therapists, educators, or gamers who benefit from haptics but possess little tactile design knowledge.

The guidelines developed here deliberately address all three groups, recognising that fruitful projects often emerge from their interaction and that the 3C is intended as an *early-stage* design aid for mixed teams.

1.2.2 Stages in a Haptic Project

Haptic system development increasingly draws inspiration from modern software methodologies, shifting from linear "build-and-ship" models to iterative approaches that integrate hardware and user-experience considerations. Agile methods such as Scrum[1] have been applied in haptic projects. For instance, Esteban et al. [151] utilized Scrum for developing a surgical training system through nine iterative sprints, each lasting two weeks. This structured approach delineates roles, responsibilities, and necessary artifacts, and was reported to support coordination in that context. Similarly, agile methodologies[2] have been employed in creating haptic simulators intended as educational tools [164]. In contrast, Conte and Nacenta [116] successfully developed HaptiQ, a device for visually impaired users, by separately managing software and hardware development. However, such separation may be impractical for more complex haptic systems. Gruenefeld et al. [201] adopted iterative design processes for ARm Haptics, a wearable AR input system, involving HCI researchers and user studies for continual refinement. Despite these examples, detailed documentation of iterative processes and activities remains limited in current literature. However, Figure 1.1 shows steps followed in the development of HCI systems, highlighting both traditional linear and iterative human-centered approaches as presented by Carey et al. [91] and Harte et al. [218]. In this thesis, the 3C guideline is situated at the *early stage* of these cycles to scaffold shared vocabulary, collaboration practices, and initial evaluation.

Given the inherently multidisciplinary nature of haptic projects, co-design method-

[1]Scrum is a project management framework emphasizing teamwork, collaboration, and iterative development cycles.

[2]Agile methodologies emphasize iterative cycles of collaboration, adaptability, and frequent delivery of functional prototypes.

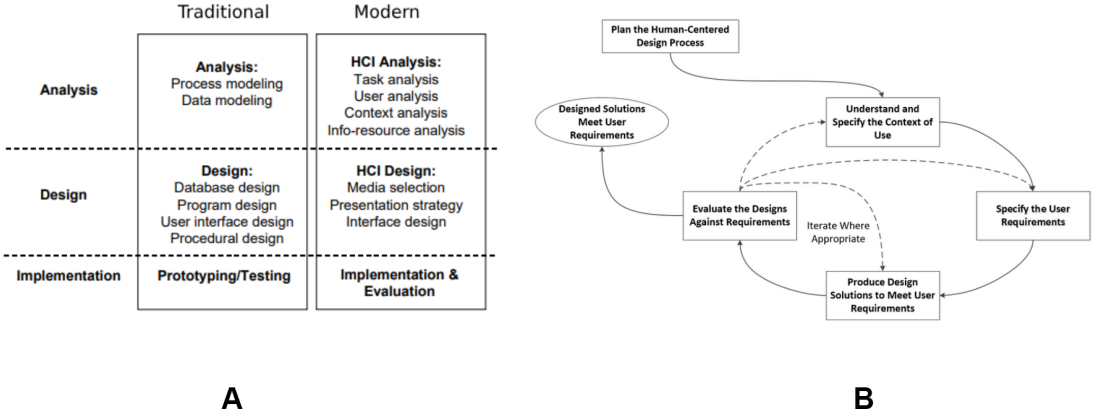


Figure 1.1: Development stages in HCI projects. A) Traditional vs Modern HCI projects [91] B) HCI Human-Centered design process [218]

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ologies facilitate collaboration across diverse teams, supporting situated design insights and usability findings. For example, a haptic drawing project continuously engaged visually impaired children throughout development, iteratively refining the interface in close collaboration [443]. Likewise, Zhou et al. [619] describe using their Shape-Kit toolkit to facilitate collaborative roles such as "crafter," "perceiver," and "holder" during prototyping sessions, enriching the design outcomes. These activities align with an *early-stage* 3C guideline, structuring Communication and Collaboration prior to formal evaluation.

Toolkits and open resources further support multidisciplinary teams by lowering barriers to prototyping and testing. Forsslund et al. [167]'s WoodenHaptics offers open-source schematics and firmware, enabling diverse users to fabricate high fidelity spatial force-feedback devices. Similarly, Compressables provides accessible, off-the-shelf pneumatics and a companion app, allowing mixed teams to rapidly prototype wearable compression haptics [148]. The availability of these resources provides shared boundary objects that sup-

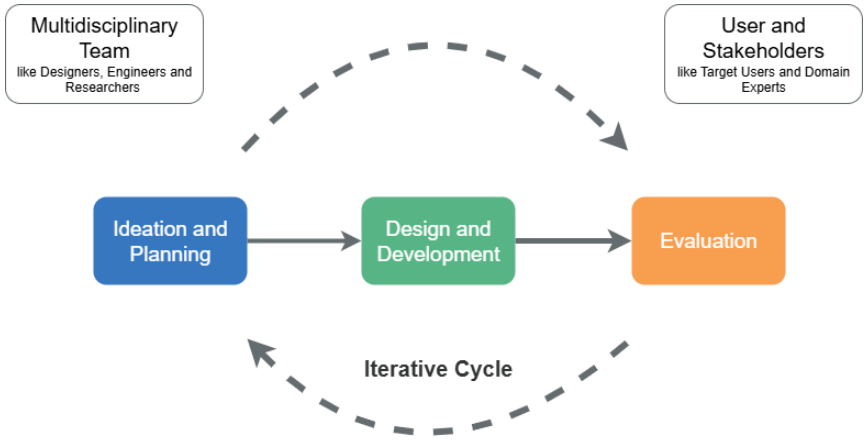


Figure 1.2: Iterative haptic development cycle showing collaboration between multidisciplinary teams and stakeholders across planning, design, and evaluation stages.

port early-stage collaboration (3C Communication/Collaboration). They provide a common tangible foundation that members with varying technical skills can build upon and discuss. This shared physical prototype becomes a focal point for communication, transforming abstract concepts into a concrete experience that the entire team can evaluate and refine.

User participation also plays a vital role in refining haptic interfaces. May et al. [367] conducted co-design sessions with deaf and hard-of-hearing children, resulting in tailored haptic art pieces and specific design guidelines. Similarly, [531] engaged visually impaired audio producers in a series of participatory workshops to develop the Haptic Wave, a device that provides a cross-modal haptic representation of digital audio waveforms for editing. Such inclusive approaches demonstrate how direct stakeholder involvement influences design outcomes. Overall, the literature underscores the importance of collaborative, iterative workflows and accessible resources as critical components in the effective development of haptic systems. Figure 1.2 visually summarizes the overall iterative agile process

in haptic projects, emphasizing the crucial roles of multidisciplinary collaboration, stakeholder engagement, and accessible toolkits —particularly at early stages of ideation and prototyping.

1.3 Enhancing the Haptic Development Workflow: Communication, Collaboration, and Confirmation

1.3.1 Barriers in Haptic System Development

Despite advances in haptic technologies, three systemic barriers continue to constrain both the innovation pace and the quality of haptic experiences delivered to end-users:

1. **Lack of Shared Understanding and Supporting Tools:** End-users and domain experts often struggle to articulate desired haptics qualities clearly. This challenge is partly due to the absence of a shared vocabulary. As a result, requirements gathering becomes complicated, leading to ambiguous and unclear specifications. Furthermore, teams lack tools and systematic processes that could help achieve a stronger collective understanding.

2. **Fragmented Collaboration and Remote Work Challenges:** Hardware engineers, firmware developers, and UX researchers typically work in parallel silos. This fragmented collaboration results in artifacts that integrate poorly or fail to adequately address perceptual constraints. These challenges become even more pronounced dur-

ing remote work, where limited informal interactions and reduced hands-on collaboration further impede cohesive integration and shared understanding across disciplines.

3. **Uncertain validation:** Tactile perception is subjective and context dependent. Currently, rigorous yet practically feasible evaluation methods for tactile experiences remain scarce. Consequently, design teams frequently must choose between informal "feel tests," which lack methodological rigor, and psychophysical studies, which are resource-intensive and demand specialized equipment and expertise. Psychophysical evaluations usually involve controlled laboratory protocols, custom apparatus, significant preparation time, and detailed statistical analysis, making their routine adoption challenging for many practitioners.

Because no widely adopted development guidelines from other fields address these gaps, teams duplicate effort, encounter preventable integration issues, and struggle to scale laboratory prototypes into reliable products. This thesis tackles the problem by studying how successful projects coordinate *Communication*, *Collaboration*, and *Confirmation* across the haptic life-cycle as *early-stage* practices. Through systematic analysis of practices using academic literature and the co-design development of a tangible haptic interface, I derive evidence-based guidelines that lower entry barriers for novice hapticians and help experienced practitioners standardise and refine their workflows, supporting better-specified and more comparable haptic systems.

1.3.2 Research Questions

The thesis asks a single overarching question:

RQ: *How can teams design, build, and validate haptic systems more effectively by improving communication, collaboration, and confirmation in the development cycle?*

This thesis addresses these questions by distilling three **critical actions** that consistently emerged in both my prior work and the broader literature: *Communication*, *Collaboration*, and *Confirmation* - the "3 C's," as shown in Figure 1.3. Each action is grounded in, and illustrated through, the research papers that form the basis of this dissertation.

1.3.3 Actions Across the Haptic System Development Cycle

Effective communication for requirement gathering [466, 143], collaboration in design and development [80, 71, 294], and early-stage evaluation (Confirmation) [452, 424, 360] are critical for the successful development of haptic systems . In this thesis, the 3C guideline frames these as *early-stage* activities—Communication (requirements), Collaboration (design/development), and Confirmation (initial evaluation).

1. *Communication between hapticians and non-hapticians* is a crucial action during the requirements gathering and planning steps of a development process. Clear communication helps to define user requirements, facilitate the exchange of ideas, and prevent misunderstandings or incorrect information. However, due to lack of vocabulary and lived experience with haptic devices, traditional requirement gathering processes used in agile and software development can be challenging. Individuals often struggle to communicate desired haptic UX and device functionality. To address this, I developed the FPI process—an *early-stage* Communication method combining

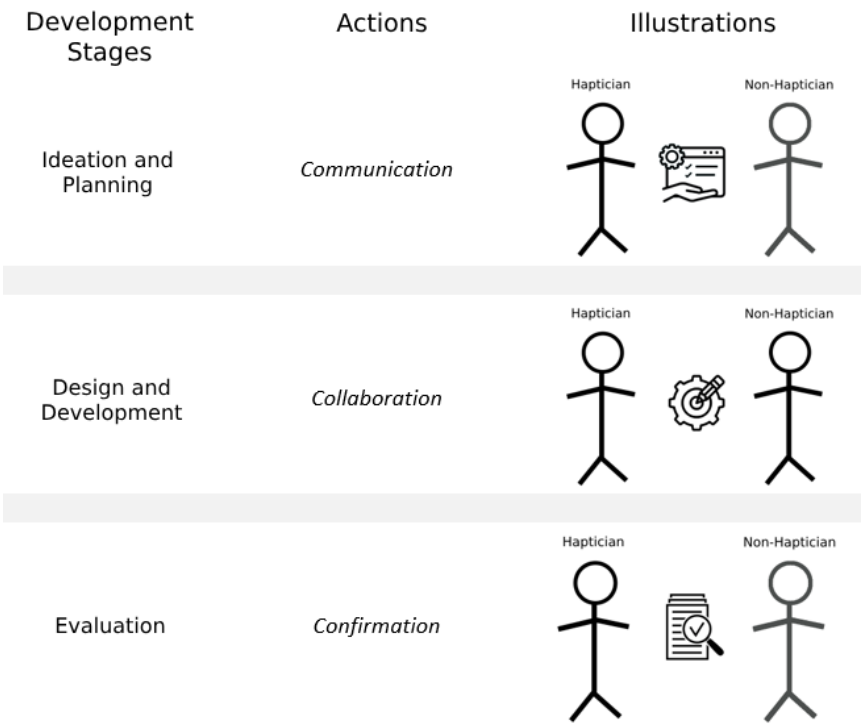


Figure 1.3: Actions evaluated at each stage of the development cycle: Communication during the Requirement Gathering stage, Collaboration during the Design and Development stage, and Confirmation during the Validation stage. Here, Confirmation is scoped to early-stage evaluation. These actions involve interactions between hapticians and non-hapticians at each stage.

hands-on exploration and examples (Feel/Play), structured imagination (Imagine), and moderated mixed-method expression. More information about the FPI process is available in chapter 3.

2. *Collaboration between hapticians and co-designers* is critical to the quality and success of haptic systems, especially in early stages. Because the field is inherently multidisciplinary, teams must negotiate values, constraints, and technical decisions through joint prototyping and shared haptic literacy. In the multi-year Sankofa project, I

worked with community storytellers, artists, educators, and engineers to co-create a restorative-justice interface. A subsequent CHI workshop demonstrated that even short-term, mixed-expert teams benefit from early boundary objects, equitable resource allocation, and clear technical grounding when tackling a focused haptic design task [581]. The Collaboration chapter (see chapter 5) distils practical guidelines from both efforts, offering strategies such as restorative-circle facilitation and tangible object or toolkit-based ideation that help maintain documented teamwork throughout the haptic development process. These practices serve as *early-stage* Collaboration scaffolds within 3C, producing testable artifacts for subsequent Confirmation.

3. *Confirmation between hapticians and end users or stakeholders* is used at the *early stage* to examine whether prototypes meet stated experiential and performance goals through user/stakeholder evaluation and transparent reporting. I investigated this through a scoping literature review of 464 empirical studies and a structured evaluation case study, both documented in the Evaluation project (see chapter 6), to characterize how early-stage evaluation is conducted and reported in recent haptics research.

1.4 Contribution

This dissertation supports the design of haptic technologies—especially for mixed-experience teams—by transforming implicit practices into structured, evidence-informed resources. Drawing insights from real-world collaborative design experiences, scoping reviews, and empirical analysis, this work provides the following contributions:

1. **Early-stage 3C Guidelines** An early-stage guideline for teams with varied haptic experience, organizing guidance around three principles. The guideline organizes guidance around three central principles:

    - **Communication:** Establishing a shared design vocabulary and concrete examples at early stages.
    - **Collaboration:** Coordinating roles, artifacts, and decision flows during early design and development.
    - **Confirmation:** Providing systematic way to evaluate whether the built haptic system meet desired experiential goals.

2. **FPI Worksheets and Prompts for Communication** The FPI toolkit offers ready-to-use worksheets, concise design prompts, and fill-in templates, complemented by real-world examples from the FPI workshop and user study. Together, these resources support novice teams in exploring and prototyping haptic experiences during early stages.

3. **Evidence-backed Guidance for Evaluating Haptic Experiences** Guidance derived from a scoping review (2018–2023) summarizing common measures, tasks, and procedures, and recommending consistent reporting fields to support comparability and replication in empirical studies.

4. **Openly Accessible Examples, Designs, and Data**

    I provide transparent documentation - shared design files from the Sankofa project, structured datasets from the scoping review, and annotated materials from both

the Sankofa collaboration and the CHI workshop. These resources enable reuse, support replication, and contribute to shared knowledge and practice for novice and experienced haptic designers.

Together, these contributions make previously fragmented practices explicit and reusable. By structuring and openly sharing evidence-informed resources, the dissertation supports inclusive, accessible, and empirically grounded approaches to early-stage haptic design for both new practitioners and multidisciplinary teams.

Chapter 2

Related Work

2.1 Introduction to Haptics

The word "haptics" comes from the Greek "haptikos" ("able to touch") and has historical and scientific roots in the study of the sense of touch [415, 221]. Pioneering work by Ernst Heinrich Weber in the 1830s established quantitative laws of tactile perception (e.g. the two-point discrimination threshold), laying a cornerstone for the systematic study of touch [261]. The term "haptics" in its modern context was formally introduced by German psychologist Max Dessoir in 1892 to denote the science of touch perception and manipulation, in analogy to optics for vision and acoustics for hearing [416]. These early philosophical insights and psychophysical experiments provided the conceptual foundation for haptics as a distinct field of inquiry into how we sense and interact through touch.

Broadly, haptic perception is now understood to comprise two complementary modalities: tactile (cutaneous) sensations that arise from mechanoreceptors in the skin, and

kinesthetic (proprioceptive) sensations that originate in muscles, tendons, and joints and convey limb position and applied force [221]. At the peripheral level, four classes of low-threshold mechanoreceptive afferents in glabrous skin—SA I, SA II, FA I, and FA II—map psychophysically onto four independent information channels (NP III, NP II, NP I, and P, respectively). This "four-channel model" explains how the nervous system decomposes vibration and pressure over a frequency range of 0.4–500 Hz [68]. In hairy skin, an additional population of unmyelinated *C-tactile (CT) afferents* responds optimally to slow, gentle stroking (1–10 cm/s) and is believed to encode the affective or social-emotional aspects of touch, complementing the discriminative tactile and kinesthetic pathways [572]. Smaller numbers of these CT afferents have also been found in glabrous skin, such as the palms, indicating that the pathway extends beyond hairy skin, albeit at much lower density [567]. Together, these channels illustrate that "haptics" is not a single sense but a multisensory construct encompassing discriminative and affective touch.

Building on these foundations, the 20th century saw haptics expand through advances in engineering, robotics, and computing. By the mid-1900s, researchers had developed one of the first force-feedback mechanisms in the form of teleoperation and telerobotic systems, allowing users to remotely manipulate objects with a sense of touch, initially motivated by hazardous tasks like handling radioactive materials in the nuclear industry [568]. This era introduced force-feedback or force-reflecting master–slave manipulators that let operators feel remote environments, foreshadowing today's haptic interfaces. Around the same time, researchers began to explore sensory substitution: using tactile stimuli to replace or augment other senses. A landmark example was Bach-y-Rita's work in the 1960s, which showed that spatial patterns of vibration on the skin could convey visual information

to blind users [46]. Such early inventions demonstrated the versatility of the sense of touch. With the advent of digital computing and virtual environments in the late 20th century, haptic technology progressed rapidly. Researchers developed electromechanical devices (e.g. the PHANToM force-feedback interface in 1993) that could render touch sensations in software-generated worlds, enabling users to feel virtual objects and forces. By the 1990s, haptics had firmly entered the realm of Human–Computer Interaction as force-feedback joysticks, gloves, and other devices began to appear, integrating touch into simulators and interactive systems [527, 568]. These developments marked a shift from treating touch purely as a subject of psychophysics to engineering touch as an interactive medium.

Today, haptics is highly interdisciplinary field at the intersection of neuroscience, psychology, engineering, robotics, and design [146, 348]. Modern haptic research and development draw on diverse expertise to create technologies that augment human capabilities through touch. The impact of this progress is evident across a wide range of application domains. In assistive and accessibility technologies, haptic feedback can substitute for vision or audio cues: for instance, vibrating interfaces help convey information to users with visual or hearing impairments [523]. In immersive digital media such as virtual and augmented reality, haptics adds a critical layer of realism, allowing users to feel virtual textures, forces, and impacts, thereby dramatically enhancing presence and engagement [590]. They are also increasingly woven into everyday digital experiences, from the subtle vibration of a smartphone notification to novel interactive art and entertainment systems that use touch to convey emotions and stories. Notably, advances in actuator technology and interface design now allow devices to convey rich tactile sensations, improving user performance and immersion across these contexts [435]. In sum, what began as a philo-

sophical and experimental exploration of the "sense of touch" has evolved into a vibrant, multidisciplinary domain. Haptics today serves as a bridge between humans and technology, underscoring its importance in human–computer interaction, skill training, accessible design, and interactive media.

2.2 Human-Centered Design

Human-Centered Design (HCD) is a user-centric approach in HCI that prioritizes end-users' needs, contexts, and feedback throughout the development of interactive systems. According to the ISO 9241-210:2019. standard, HCD aims to make systems "usable and useful by focusing on the users, their needs and requirements, and by applying human factors, ergonomics, and usability knowledge" [5]. Nielsen's seminal heuristic evaluation guidelines provide foundational principles for applying HCD, emphasizing factors such as visibility of system status, error prevention, consistency, flexibility, and aesthetic and minimalist design [392]. Additionally, Norman's exploration of affordance, visibility, and intuitive controls asserts the importance of aligning a product's design closely with users' mental models and expectations, thus reducing cognitive load and preventing user errors [138]. Building on these frameworks, HCD practices have proven effective across diverse application domains including web and mobile interfaces, accessibility technology, and interactive physical devices by consistently increasing usability, efficiency, accessibility, and user satisfaction through iterative evaluations and refinements [354, 392].

HCD has become a cornerstone of research on touch-based interfaces. One specific strand within HCD is participatory design, an approach in which end-users act as co-

designers rather than passive study participants. By involving users directly in the design process, researchers can surface tacit needs and ensure that resulting interfaces fit real-world practices.

The same user-involved mindset is now permeating haptics research. A critical review of haptics in virtual reality observes that the field is "gradually complementing the functionality approach with HCD principles," signalling a broader shift toward practical, user-centred solutions [470]. Together, these efforts demonstrate how agile, user-involved design processes are increasingly integrated with technical innovation in haptics.

Despite this progress, HCD in haptic system development remains less established than in visual or auditory domains. Researchers have pointed out a lack of standardized design guidelines and evaluation frameworks for haptic interfaces [494, 281]. Unlike graphical user interfaces or audio feedback, which benefit from decades of usability research and well-defined heuristics, methods for haptic interaction design are "not as well developed" as their visual and auditory counterparts [325]. This gap means that many haptic technologies are still engineered in an ad hoc, and their user experience outcomes are not as well validated. The nascent adoption of HCD in haptics thus highlights both the potential and the need for more rigorous, user-centered practices. This observation sets the stage for the next section, which focuses on emerging UX guidelines in haptics and multimodal interaction design, an area aimed at formalizing design best practices for the sense of touch in concert with other modalities.

2.2.1 UX Guidelines in Haptics

Modern UX have become increasingly well-established, drawing on decades of research in human touch perception and interaction design [219]. Unlike visual or auditory UX, haptic design must accommodate a diverse set of mechanoreceptors and the inherently bidirectional nature of touch [206]. This means that UX go beyond traditional UI principles, explicitly integrating knowledge of human sensory thresholds, adaptation, and motor feedback. For example, designers must consider that haptic feedback involves both tactile and kinesthetic aspects, each with distinct resolution and fatigue characteristics [206]. These unique constraints demand careful tuning of stimuli so that vibrations or forces are noticeable but not overwhelming, and so that touch cues remain clear under varying context and repeated use.

Early work defined the tactile vocabularies that still guide haptic UX. MacLean's haptic icons are short, computer generated vibrations that mark events such as notifications [349]. Brewster's tactons likewise encode messages for nonvisual use [77]. By tuning waveform, rhythm, frequency, amplitude and duration, both studies produced cues that are easy to tell apart and easy to interpret. Two lessons emerged, namely that signals must be perceptually salient, and similar meanings should always feel similar. Later research folded these lessons into broader UX guidance, stressing that haptics stay intuitive, quick to learn and reliable across contexts.

Over the last decade these insights have been distilled into platform guidelines for phones and wearables (e.g Android, iOS, watchOS) [4, 2]. They recommend short, crisp pulses rather than prolonged "buzzes", mapping signal strength to event importance, and

synchronizing haptics with concurrent visual or auditory cues to achieve multimodal coherence [4]. A 10–20 ms "click" for button confirmation is a canonical example: salient, brief, and low-fatigue.

Translating such recommendations into practice, however, remains difficult—especially for teams new to haptics. Observational studies show that novice hapticians frequently skip design decisions experts consider fundamental, such as whether a cue should reinforce an existing modality or stand alone [493]. Consequently, researchers call for tools that embed psychophysical knowledge, automate parameter selection, and surface best practices during design [493, 206]. In short, the field now agrees on core principles - discriminability, consistency, multimodal alignment, and iterative user testing, but the pressing challenge is making those principles actionable for everyone who designs with touch.

2.2.2 Multimodal Interaction Design Guidelines in Haptics

Multimodal interaction design guidelines considers the integration of tactile stimuli with other sensory channels, such as visual and auditory modalities. Effective multimodal interfaces leverage human sensory and cognitive capabilities, enhancing interaction precision, effectiveness, realism, and overall user satisfaction by providing complementary or redundant sensory cues [409]. According to Hale and Stanney, designing multimodal interactions requires careful management of perceptual dominance (e.g., visual dominance over haptics), cross-modal congruence (ensuring consistent interpretations among modalities), and cognitive factors such as attentional demands and working memory load [205]. Proper guidelines must therefore specify optimal parameters—stimulus synchronicity, cue redun-

dancy, temporal integration windows—and consider potential cognitive overload resulting from inappropriate multisensory combinations [506, 205].

In haptics, multimodal guidelines are particularly important given touch's relatively limited informational bandwidth compared to vision or audition. Multimodal integrations can augment this limitation by clarifying ambiguous tactile sensations with corresponding visual or auditory feedback, reinforcing task-relevant information, and reducing perceptual errors [506, 170]. Studies by Sigrist et al. [506] emphasize the effectiveness of combining visual cues with tactile sensations to support learning complex motor tasks and increase overall user performance, especially in assistive and rehabilitative contexts . Furthermore, empirical haptics guidelines provided through multimodal contexts emphasize adjusting parameters explicitly to cognitive capacities, preventing sensory conflicts, and systematically assessing interactions through rigorous user studies and realistic task scenarios [170, 205]. However, the literature identifies ongoing gaps—such as limited validation across different contexts, a lack of standardized multimodal-haptic design, and insufficient empirical evaluation of cognitive loads and perceptual interactions [204, 482], necessitating further research and development of precise, empirically validated multimodal interaction guidelines.

2.3 Guidelines for Hardware and Software Development

Structured guidelines for hardware and software development substantially enhance multiple dimensions of system quality, including design effectiveness, testing rigor, maintain-

ability, and usability [60, 38, 386]. Adopting standardized approaches such as the Software Development Life Cycle (SDLC)[1] and agile methodologies contributes demonstrably to reduced software defects, improved performance, better user experiences, and reusability of code [322, 223, 521]. Similarly, structured hardware development methodologies—including the V-Model[2], Design for Manufacturing (DFM) [431], agile hardware frameworks, and Design for Test (DFT) methods—promote rigorous requirement specification, effective testing, and facilitated system maintenance, thus significantly improving overall hardware quality [555, 396, 318].

Within the specialized haptics domain, hardware design guidelines have been detailed extensively to support complex device design and integration practices. Existing literature provides precise, yet mostly independent, recommendations for critical hardware parameters, including actuator selection, mechanical construction ergonomics, optimal hand and body positions, response times, inertia management, and system mass constraints [547, 403]. Additional specific guidelines have been suggested for robotics-based haptic systems—such as human-robot interfaces, teleoperation robots, and surgical robotics—emphasizing precise control, safety, and accurate force feedback [34, 28, 197]. Comprehensive performance metrics guide effective hardware specification in the domain, explicitly noting critical considerations such as force magnitudes, friction dynamics, actuation responsiveness, frequency bandwidths, and mechanical impedance characteristics [472, 471]. It should be emphasized that these publications offer fragmented guidelines rather than a single, unified

[1]The Software Development Life Cycle (SDLC) is a structured framework guiding software development processes through distinct phases - including analysis, design, coding, testing, deployment, and maintenance, to facilitate consistent delivery of efficient, user-aligned systems.

[2]The V-Model emphasizes continuous validation and verification throughout all stages of the development cycle, ensuring alignment between implemented products and specified user requirements.

design methodology. In contrast to holistic development frameworks such as the V-Model, Design for Manufacture (DFM), or Design for Assembly (DFA), the haptic literature predominantly delivers isolated prescriptions addressing one aspect of a device at a time. Consequently, designers still face the challenge of stitching together disparate rules when moving from initial concept to fully-realized haptic product. International standards such as ISO and CEN further contribute application-specific benchmarks, supplying manufacturers and developers with ergonomic guidelines and structured methods for system analysis, design evaluation, and compliance [550, 57, 508].

Software guidelines for haptic systems similarly stress rigorous development practices, emphasizing real-time responsiveness, algorithmic stability, and modular architectures. Widely recommended practices include adopting stable rendering algorithms, as well as implementing modular software designs to enhance maintainability, scalability, and interdisciplinary integration [408]. Such standardized approaches foster robustness and clarity in software implementation, aligning closely with structured methods established in broader software engineering contexts.

Several authors have therefore called for guidance that explicitly links hardware choices, software performance, and user-experience targets within a single, validated workflow [482, 120]. However, the haptics field still lacks a comprehensive, start-to-finish design framework comparable to the V-Model or Design-for-Manufacture approaches used in other engineering disciplines.

2.4 Core Challenges in Haptic Development

Developing effective haptic systems inherently involves integrating diverse expertise from engineering, software development, interaction design, and human perception research. The multidisciplinary nature of such projects often creates considerable complexity, posing unique challenges related to how teams communicate, collaborate, and evaluate their work. The section below details these central challenges, drawing particularly upon gaps highlighted in prior academic research.

2.4.1 Communication Challenges in Haptics

Despite increasing interest in haptic interaction, researchers consistently note that haptic design is still a largely ad hoc process without clear standards or frameworks. Studies of novice haptics report that engineers and designers enter haptics inexperienced and without dedicated support: they rarely have tools and guidelines for creating multisensory (including haptic) experiences [493]. Instead, teams tend to rely on personal intuition and focus on low-level technical tuning while overlooking conceptual objectives [493]. This means haptic projects often advance on a purely trial-and-error basis, and engineers and designers have no shared reference for discussing or planning touch sensations. As Elbaggari [146] notes, haptic design remains so complex that its *knowledge, skill, and tools* are largely confined to specialists. In sum, the literature on haptic practice makes clear that current development teams operate without well-defined processes or artifacts to guide collaboration, leading to divergent individual approaches rather than coordinated design.

A prominent symptom of this gap is the absence of a common vocabulary for haptics. Multiple authors emphasize that there is no agreed lexicon for describing tactile effects. For example, Israr et al. [250] explicitly identify the lack of both haptic vocabulary and authoring methods as a key challenge for designing expressive tactile feedback. Likewise, Seifi et al. [493] call for developing representation as well as haptic vocabulary for efficient communication within the community . In practice, team members often resort to vague metaphors or sensory analogies to communicate about haptics. In a recent design study, participants noted that because no words exist, they can kind of only express [a haptic idea] through feeling it [619]. This lack of language forces reliance on ad hoc demonstrations (e.g., showing an effect rather than naming it), which can kickstart dialogue but do not scale to rigorous design reasoning. No standard taxonomy (like color palettes for visuals or icon grammars for sound) has been established, so engineers speak in voltages or frequencies and designers describe sensations subjectively (e.g., *buzzing* or *throbbing*), with little common ground. Even early user-centred research confirms this problem: users tasked with describing touch experiences produce only a few concrete adjectives, reflecting an underlying lack of a haptic language for rich tactile qualities [121].

Given these deficits, one would expect novel frameworks or toolkits to have emerged, but existing efforts remain piecemeal. A small number of prototype toolkits and methods (often produced in research contexts) aim to fill parts of the gap, but each addresses only a narrow slice of the problem. For example, TactJam and Shape2Vibe systems have been proposed to support co-design of vibrotactile effects, allowing team members to sketch and swap patterns [551, 581]. These studies explicitly note that sharing haptic designs is usually a feature which is typically lacking in off-the-shelf tools. Similarly, Zhou et al.

[619] introduced Shape-Kit, a hybrid craft kit for designers to physically prototype on-body haptic motifs; participants found it valuable for sparking ideas and starting the conversation about touch, yet it still functions essentially as an informal playground rather than as a rigorous design language . Other attempts include TactorBots and wearable prototyping toolkit, which let people explore tactile gestures [620], and storytelling-based methods [250] that map narrative events to haptic effects. But these examples mainly illustrate the challenge (they are evaluated with small user studies) rather than providing generalizable theory or standards. In particular, tangible toolkits often end by confirming that participants cannot precisely name or reason about touch: one study's respondents needed tangible shapes to share patterns because conventional language failed them [551].

In summary, the related literature reveals a consistent gap . While many papers recognize that haptic development is difficult, few actually establish validated practices for cross-disciplinary communication. There are no widely adopted design guidelines or ontologies that span engineering and UX perspectives, and no consolidated frameworks for organizing haptic effects. Existing research on haptics often focuses on perception or specific hardware, and design studies highlight idiosyncratic craft processes, but none have produced a standardized vocabulary or modular toolkit for broad use. As Schneider et al. [482] conclude, haptic designers follow familiar design processes in the wild but still face specific challenges when working with haptics, underscoring the need for concrete community resources. Therefore, the field is still searching for the equivalent guide to help team communication as it remains fragmented and informal.

2.4.2 Collaboration Challenges in Haptics

Haptic development inherently spans multiple domains – mechanical engineering, robotics, software engineering, electronics engineering, user-experience design and more – yet these activities often proceed in isolation. For example, Schneider et al. [481] observe that haptic researchers "often re-invent the wheel" across devices, software, and design, calling for an agenda to treat haptics as "a united design discipline". Similarly, Seifi et al. [494] note that "experience designers are rarely engineers," lamenting that decades of device innovations remain "buried in a fragmented literature". These analyses highlight that today's academic haptics lacks shared frameworks or repositories to integrate diverse expertise, leading to redundancy and inefficiency in project workflows.

A deeper issue is the lack of formal recognition or definition of roles within multidisciplinary haptics teams. Elbaggari [146] argues that the identity of a "haptician" is fluid and often self-constructed, shaped more by community engagement than institutional structures. In academic teams, this fluidity can blur role boundaries, making it unclear who is responsible for integrating hardware with interaction design or translating experimental results into user-facing experiences. Without clearly defined collaboration protocols or shared disciplinary anchors, contributors are left to negotiate responsibilities and workflows informally, increasing the potential for misalignment.

Research focusing on haptics echoes these challenges. Schneider et al. [482] conducted interviews with professional hapticians and explicitly mapped the field's collaborative ecosystem, finding that although designers follow a familiar process, they face specific challenges unique to haptics. In particular, they note that co-design of vibrotactile interfaces is ham-

pered by tool limitations: sharing haptic design artifacts is hard to do with current design tools. In practice, this means hardware prototyping constraints, software integration, and user-testing often proceed on disconnected schedules, causing coordination breakdowns. To date, however, these insights have not been distilled into concrete collaboration models or process guidelines; hapticians cope on an ad hoc basis rather than following a validated framework.

In summary, existing research—both within haptics and in adjacent HCI fields—flags many challenges of multidisciplinary work but offers little in the way of concrete solutions tailored to haptic teams. Schneider et al. [481] and Seifi et al. [494] explicitly call for unified practices to share knowledge across devices, software, and experience design, yet their recommendations remain conceptual. Elbaggari [146] findings further reveal that even the notion of expertise in haptics is community-driven and informally defined, underscoring the absence of structured collaboration mechanisms. This gap is significant: without guidelines for team collaboration, haptics projects risk repeated reinvention and miscommunication.

2.4.3 Confirmation (Evaluation) Challenges in Haptics

In HCI, evaluation methods are highly developed and standardized. Established instruments such as the System Usability Scale (SUS) [81] and the ISO 9241 series of ergonomic standards [393] provide widely accepted usability criteria. The maturity of HCI evaluation is also evidenced by recent meta-analyses: for example, Dey et al. [133] systematically reviewed a decade of augmented reality usability studies, Merino et al. [373] surveyed evaluation practices in mixed/augmented reality, and Ogunyemi et al. [406] mapped HCI

practices in software development. Together, these works underscore a coherent, systematic approach to evaluation in HCI. By contrast, haptic interface research has not converged on similar frameworks; haptic evaluation methods remain fragmented and lack the unified standards seen in HCI.

As Fazlollahi et al. [161] observe, the specifications do not capture performance quality in a consistent or meaningful way. Haptify is one of the few recent efforts to introduce structured benchmarking in haptics, but its scope remains narrow, focusing primarily on grounded force-feedback systems [160]. In general, haptics studies use ad hoc tests or small-scale user trials rather than standardized metrics [482]. Although the recently validated HXI [500] marks an encouraging first step toward a shared usability questionnaire for touch feedback, it remains too new for widespread adoption and still lacks complementary objective benchmarks.

Recent work in specialized haptic domains highlights this fragmentation. For example, the emerging field of electrotactile feedback lacks standardized hardware and evaluation frameworks, resulting in highly varied device constructions. Consequently, most studies rely on psychophysical experiments and subjective reports, making results difficult to compare or reproduce due to high variability and the absence of objective, real-time assessment models [589]. Each lab must therefore calibrate its own device and report results in its own terms, making cross-paper comparison difficult. Electrotactile research thus mirrors the broader haptics landscape: evaluation practices remain ad-hoc rather than anchored in shared, validated protocols.

Likewise, attempts to model the haptic experience (HX) underscore the lack of consensus tools. Kim and Schneider [284] proposed a comprehensive HX model with design

parameters (e.g. timeliness, intensity), usability requirements, and experiential factors (e.g. harmony, realism) [284]. Sathiyamurthy et al. [477] even derived an 11-item, 4-factor model (Realism, Harmony, Involvement, Expressivity) based on user studies with multiple haptic modalities. These are promising efforts, but they use different constructs and have not been validated across domains. In practice, no single questionnaire or framework has emerged for haptic UX. Thus, designers lack a general-purpose standard instrument for evaluation.

Evaluation practices in affective and assistive haptics remain underdeveloped.Affective haptics is largely exploratory: MacLean [348] emphasizes that we need additional paths to translate affective haptic science findings into actionable frameworks, implying that current methods are fragmented. Evaluations of emotional haptic feedback typically rely on varied self-reports or ad hoc measures, rather than standardized affect scales. Similarly, Vyas et al. highlight that affective haptic research varies widely in purpose and disciplinary origin, complicating efforts to establish unified evaluation approaches [556]. In assistive haptic technology (e.g. for blind users), reviews find comparable shortcomings. Jiang et al. [259] identify limitations on user study such as lack of device comparisons, inconsistent subjective scales, and almost no real-world testing. In many cases, only a narrow user group (often young, sighted laboratory volunteers) is evaluated.

Overall, haptic research still lacks the standardized evaluation protocols and validated tools that are common in other fields. Apart from the newly introduced HXI [500] - a promising metric for assessing haptic experiences methods remain scarce, and this absence continues to be a major bottleneck in haptic system development.

2.5 Need for an Integrated Communication, Collaboration and Confirmation Guidelines

Despite the progress outlined above, a major gap in the literature is the absence of a holistic framework that brings Communication, Collaboration, and Evaluation together to support haptic development. Prior work has typically addressed these facets in isolation: some papers provide hardware/software design guidelines, others emphasize team dynamics or propose new user experience metrics. What is lacking is a unifying development methodology that accounts for technical and human factors concurrently. As researchers have noted, building a haptic system requires more than just selecting the right technology or design parameters; understanding the people involved and the process being followed is equally critical [482]. In practice, hapticians often face multifaceted challenges: they must work across disciplinary boundaries, communicate design intent and requirements clearly, and iteratively refine the user experience through evaluation, yet there is no single playbook to navigate these interdependencies. The consequence is that haptic projects can suffer from miscommunication, fragmented workflows, and ad-hoc evaluation, ultimately slowing innovation in the field. Our review of related work underscores a clear need to fill this gap. We need a guideline that explicitly supports communication (common language, stakeholder dialogue), collaboration (role clarity, coordinated workflows), and evaluation (ongoing assessment and feedback loops) as equally important pillars of haptic system development. Such "3C Guidelines" would offer a unified framework ensuring that haptic teams build the right product and build it right . This dissertation articulates and outlines the 3C

guideline, formalizing haptic development workflows.

2.6 Summary of Key Research Gaps

Existing research highlights several critical gaps in multidisciplinary haptics development, emphasizing the complexity that arises from integrating engineering, software, interaction design, and user-experience expertise. The primary research gaps identified are:

- **Communication Challenges:** Communication among hapticians is significantly impeded by tool limitations and disconnected schedules for hardware prototyping, software integration, and user testing, which frequently results in communication breakdowns and isolated workflows.
- **Lack of Clearly Defined Roles and Collaborative Structures:** Haptics teams frequently lack formal recognition and definition of roles, resulting in blurred responsibilities and informal negotiation of workflows. This ambiguity increases chances of misalignment and redundancy in project activities.
- **Limited Standardized Design and Evaluation Methods:** Unlike other areas in HCI that benefit from established and widely accepted evaluation methods, haptic development lacks such widely recognized usability criteria and evaluation instruments tailored specifically to haptic experiences, decreasing consistency and reliability in haptic systems assessment.
- **Absence of Integrated Interdisciplinary Guideline:** Although some specific hardware and software development guidelines exist, combining these into a com-

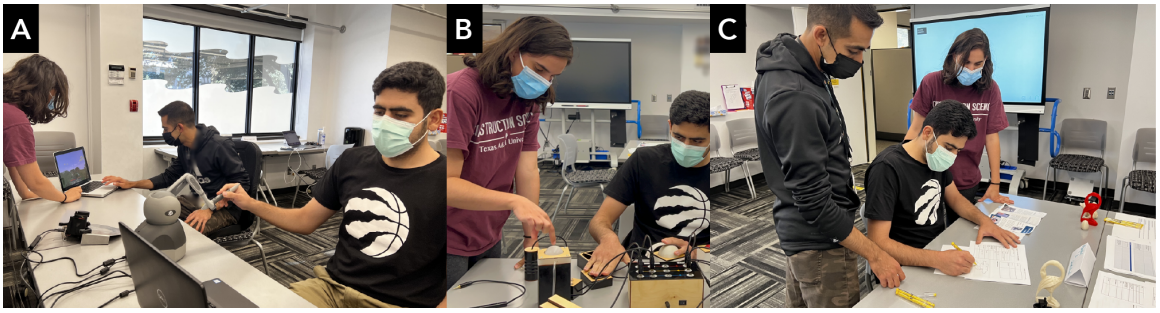
prehensive guideline that actively supports interdisciplinary collaboration remains challenging and is generally missing in current practice. This gap leads to inefficient collaboration and disjointed project activities.

This dissertation responds to these gaps by: (1) introducing artifacts and practices that provide a shared haptic vocabulary and example-first co-design (Feel–Play–Imagine)—including Hands-on Exploration, Structured Imagination, Mixed-Methods expression, curated Examples, and thoughtful Moderation (Communication); (2) specifying collaboration scaffolds in a tangible-VR context—boundary objects, role/ownership maps, synchronized reviews, trust-building, common ground, technical-competency sharing, motivation alignment, and structured negotiation leading to shared ownership (Collaboration); and (3) distilling reporting checklists and an evaluation taxonomy from recent haptics studies (2018–2023) to support sound Measurement Practices, Balanced Sampling, Contextual Validity, Transparent Documentation, and Ethical Transparency (Confirmation).

Chapter 3

Communication: Requirement Gathering and Planning

This chapter examines the critical role of communication within interdisciplinary haptic design teams and presents the Feel-Play-Imagine (FPI) method to address early-stage communication challenges. Haptic technology offers diverse interactive opportunities yet remains difficult to discuss clearly due to limited experiential references and shared vocabulary. To bridge this gap, FPI provides a structured approach where participants first experience polished haptic examples ("Feel"), explore and experiment playfully with various haptic modalities ("Play"), and then collaboratively imagine potential design outcomes through narrative-driven discussions ("Imagine"). Evaluations conducted through a co-design workshop and a formal lab study with ten expert storytellers demonstrate that FPI effectively fosters hands-on experiential learning, supports informed design decisions, structures productive design conversations, and underscores the need for multimodal and



(a) Introduction: Haptic Mini-Tour and Tickle Trunk

(b) Structured Imagination: Worksheet

Figure 3.1: The image shows the two main components of the FPI process: (a) "Feel and Play", where storytellers explore haptic devices like the Tickle Trunk for prototyping experiences; and (b) "Imagine", where storytellers use a worksheet to structure and integrate haptics into their narratives.

gestural forms of communication in haptic and tangible design discussions.

3.1 Introduction

Creators have more opportunities than ever to employ haptic feedback in interactive systems. While much of the existing literature has focused on vibrotactile feedback, haptics encompasses a broader range of modalities, including force feedback, surface texture simulation, temperature modulation, and even skin stretch [350, 222, 587]. These modalities can be used not only for functional interaction but also for enriching narratives, making stories more immersive and emotionally engaging through physical sensations [250, 616]. This diversity enables more expressive and context-specific tactile experiences, but also presents challenges for designers who may be unfamiliar with the nuances and capabilities of these modalities. Emerging systems now combine multiple forms of haptic output to en-

hance realism and engagement, pushing beyond simple vibrations to evoke richer sensory responses [321]. This potential for rich, embodied interaction makes haptics an increasingly valuable medium for storytelling applications, where conveying presence, emotion, and context through touch can deepen audience engagement.

A proliferation of new haptic devices have been used in different areas such as robotics, medicine, education and virtual reality [165, 208, 319], or in storytelling to enrich the audience experience, provide better immersion and improve concentration while listening to stories [501, 473, 616]. However, the absence of a standardized vocabulary and lived or on-hand experience restricts creators in the early stages of design and development [482, 184].

When designing haptic systems, hapticians (makers of haptics) [482] assemble diverse teams, including software and hardware engineers, people with psychology and design knowledge, and domain experts. Team members must take care to communicate across disciplinary boundaries to be successful. Communication and discussion is difficult enough between hapticians, but can completely break down with non-haptician stakeholders like co-designers, clients, or external team members. People unfamiliar with haptic technology lack a lived experience of what the technology feels like or can involve, and hapticians have limited ability to demonstrate its capabilities. This limits essential design activities like gathering requirements [13] or establishing mutual understanding and imagining futures [73].

Previous work has looked into eliciting technical requirements of the devices like specification of motors, actuators, and sensors [113], using metaphors to help elicit designs for a single device [83], or enabling customization of haptic effects [310, 495]. Other approaches

use high fidelity designs in the initial stage, which requires time and involvement of experts [144, 411], which might not always be possible for every project. While helpful for each of their intended goals, these approaches are tied to a specific design decision (e.g., actuators, metaphors) or devices, typically in support of a clear utility goal like guidance, such as spatial vibrotactile orientation cues or skin-stretch way-finding aids [587, 98]. Instead, we aim to support creators in retaining creative control over their work and provide the opportunity to simultaneous explore the materiality of different devices [575, 163] and discuss the potential goals of those devices.

To address the critical communication gap identified above, this chapter introduces the Feel, Play, and Imagine (FPI) process. The main objective behind developing FPI was to facilitate more effective communication and ideation sessions between hapticians and non-haptician stakeholders, particularly in creative contexts such as interactive storytelling. Taking inspiration from agile practices—where iterative feedback loops encourage rapid experimentation, collaboration, and user-driven insights [361] - the FPI method encourages creators to engage hands-on with diverse haptic modalities early in the design process. This approach deliberately avoids initial focus on technical specifications, focusing instead on fostering experiential understanding, collecting designer insights, and nurturing the articulation of imaginative, user-centred visions for haptic and tangible experiences.

3.2 Related Works

The chapter 2 reviewed the key challenges of haptics research and development. This section narrows that broad lens to the specific literature that motivates the Feel–Play–Imagine

process introduced in this chapter.

3.2.1 Interactive Storytelling in HCI

Previous studies have found that interactive technology for storytelling allows users to engage, collaborate, and share their experience among peers [55, 29]. Specifically, for children, KidPad and Klump [55] are two collaborative storytelling technologies that were designed to encourage them to work as a team in order to create and tell stories together. StoryRooms [29] is another study where children build and share physical storytelling experiences using low-fidelity and high-fidelity props.

3.3 Feel-Play-Imagine (FPI) Process

We initially developed the FPI process in the context of a larger research project, Digital Oral Histories for Reconciliation (DOHR) [188, 334]. The DOHR project aims to share the narratives of former residents of the Nova Scotia Home for Coloured Children, supporting the Province of Nova Scotia's Restorative Inquiry into their experiences as children in the institution. This project is particularly focused on working with storytellers who are interested in incorporating haptic feedback into an existing VR experience, with the goal of promoting social justice and amplifying the voices of marginalized communities [520, 491]. The narratives explored in this project touch on sensitive subjects, such as the historical harms of institutionalized racism. These stories are planned to be shown as a museum exhibit and included in grade 11 history courses where a wide range of audiences are involved. Our collaborating storytellers were interested in taking advantage of haptic technology to

expand their storytelling capabilities to attract more people, enrich the stories themselves, and potentially make the experience more accessible. Critically, the restorative process involves the principle of subsidiarity, where decisions are made by those most affected by the outcomes [334].

Our project, aimed at integrating haptics into the DOHR VR experience, brings together a diverse team of experts from various disciplines including Communication Arts, Human Computer Interaction, Social Development, Engineering, Law, Psychology, and community storytelling. During our initial online meetings, several members of our team lacked an embodied understanding of haptics and its context, making it challenging to brainstorm ideas involving haptics. As we arranged for an in-person meeting, time was also limited: we had a single day available for a workshop. In order to effectively engage in mutual learning and gather the necessary design requirements for a new haptic component, the haptics team needed to devise a process that would not only quickly familiarize our collaborators with haptics but also allow them to retain creative control. Prior research into haptic experience design confirms this more generally: individuals unfamiliar with haptics "don't really know what you can do with haptics" [482].

To solve this problem, we decided we needed to accomplish two things:

1. We wanted to provide a quick and engaging introduction to haptics with multiple hands-on experiences. After reflecting on this goal, and realizing the importance of physical touch [482] and value of libraries of different effects that support meaningful language [250, 485, 496], we decided that this introduction should consist of collection of haptic experiences to allow people to understand where and how haptics might fit

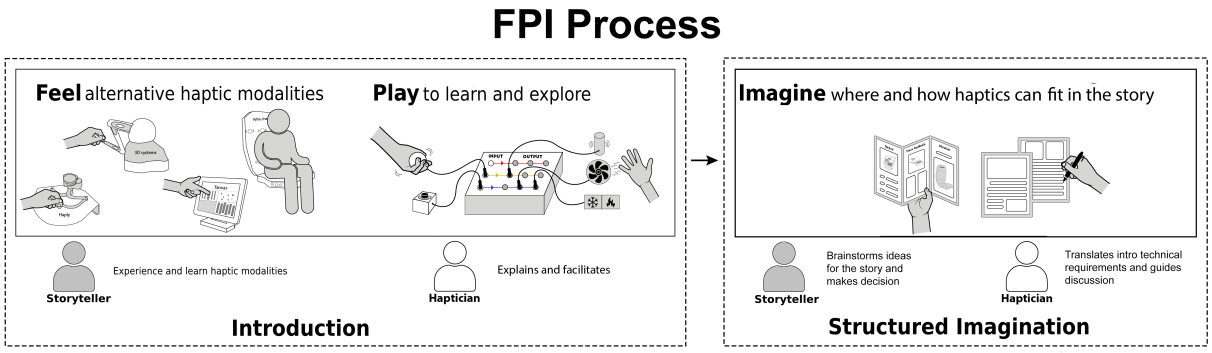


Figure 3.2: The FPI process. Storytellers to feel and play haptics to experience and learn alternative haptic modalities, and finally imagine where and how haptics can fit in the story. Our implementation of the FPI process. For **feel** and **play**, we gave a Mini-Tour of 4 haptic devices to show haptics in context and Tickle Trunk to showcase different haptic modalities. For **imagine**, we designed a Worksheet for users to brainstorm where to use haptics in their stories.

in their story. We wanted these examples to provide a realistic understanding of how haptics is used in the commercial space and with custom devices. Through discussions in the haptics team, we arrived at a potential way to introduce haptics by feeling and playing with different haptic sensations, from vibration to changes in temperature to force feedback to shape change displays and more. Ideally, collaborators could quickly test them in various formats, such as combining modalities or trying them on different body locations [15, 534, 391].

2. Our goal was to empower storytellers by providing them with the creative freedom to seamlessly incorporate haptics into their narratives without the constraints of pre-existing devices or prototypes. We aimed to enable designers and developers to explore design requirements at the earliest possible stage. By allowing the design requirements to originate from the story itself, storytellers can determine how, when,

and where haptics can be integrated into their existing narratives. This could involve major story elements such as characters, settings, plot, and resolution. As suggested by MacLean et al. [350] and Seifi et al. [493], we had to find ways to guide non-haptician storytellers in their design decision process.

Adhering to a key principle of the co-design process to empower of ideas of the co-designers [603], we created the FPI process (Figure 3.2). It involves three steps: Feel, Play, and Imagine. 'Feel' and 'Play' introduce the concept of haptics, while 'Imagine' supports exploration of haptics within the story. We implemented this process in our context of VR storytelling with a Haptic Mini-Tour and Tickle Trunk for Feel and Play, and a custom-designed Worksheet for the Imagine step.

3.3.1 Feel and Play (Introduce)

The Feel and Play steps, which together form the Introduction step, provide an opportunity for non-haptician storytellers to physically interact with the devices, thereby gaining a broad understanding of their functionality and potential applications. The haptician guides the participants through this process, providing clear explanations and demonstrations of each device. Storytellers are then given the opportunity to interact with the devices themselves, using demo applications to experience the haptic feedback firsthand. This interactive approach allows participants to spend time to experience the capabilities of the devices, as they can directly feel and manipulate the haptic sensations.

The devices included in the Feel-Play step offer a variety of input and output modalities for interaction, allowing participants to experience a wide range of haptic sensations . These

diverse devices not only facilitate the physical sensation and experience of haptic feedback, but also provide storytellers with the opportunity to experiment with various modalities. This offers a chance to learn and understand the system better. The concept of enhancing user experience through play-based learning approaches is similar to techniques previously investigated in the realm of HCI for children's education and VR [63, 293, 499, 182].

The difference between Feel and Play is a contrast of purpose, intent and form similar to depth and breadth. Table 3.1 highlights the different goals of these two feature during the introduction of haptic feedback.

Feel step		**Play step**
Fixed	$\longleftrightarrow$	Flexible
Vertical	$\longleftrightarrow$	Horizontal
Definite	$\longleftrightarrow$	Tentative
Complete	$\longleftrightarrow$	Exploratory
Experienced	$\longleftrightarrow$	Manipulated
Integrated	$\longleftrightarrow$	Modular

Table 3.1: Differences between the *Feel step* and the *Play step*. The *Feel step* gives context through polished, multimodal haptic experiences, whereas the *Play step* encourages hands-on exploration of individual modalities. Layout inspired by Buxton's Sketch–Prototype continuum [84].

Haptic Mini-Tour and Tickle Trunk

We support the feeling and playing of haptics in the context of using Haptic Mini-Tour and Tickle Trunk.

- The Haptic Mini-Tour is a set of commercial haptic devices for users to experience different types of haptic systems to give a sense of how haptic feedback might appear

Devices	Modality	Software Experience
Haply	Hand movement in a plane with 2DOF Force Feedback	2D Maze with realistic physics
3D systems Touch	Stylus manipulated in three-dimensional space with 3DOF Force Feedback	Example games and activities
Avengers Vybe Haptic Gaming Chair	Pressing buttons or in-game triggers and receiving on-body vibrations	Minecraft with designed vibration effects [484]
Tanvas	Touchscreen with surface haptics (friction manipulation)	Demo applications including shaving and dusting fossils
Tickle Trunk	Variety of input and output widgets (see Figure 3.4	*none*

Table 3.2: Devices included to allow Feel and Play of haptic feedback

in a final deployed system (Figure 3.3). The Mini-Tour can be customized with any high-fidelity haptic devices and their associated experiences, depending on the desired context. For our workshop and expert study, we utilized four commercial devices available in our lab: Haply, 3D systems Touch, Avenger Vybe Haptic Gaming Chair, and Tanvas. Detailed information about each device and the specific games used during our study can be found in Appendix section A.1.

- The Tickle Trunk [1] [2] (Figure 3.4) is a custom built tangible toolkit that allows users to experiment with tangible, physical interactions with a wide range of haptic modalities like pressure, shaking, heat, vibration and force-feedback. It uses plug-

[1]The name comes from the Tickle Trunk used by acclaimed children's entertainer, Mr. Dressup, who could reach into the trunk to grab whatever costume or prop he needed at that moment.

[2]Further information on Tickle Trunk can be found in the master's thesis "Tickle Trunk: A Toolkit for Playful Exploration and Brainstorming with Haptics," [43].

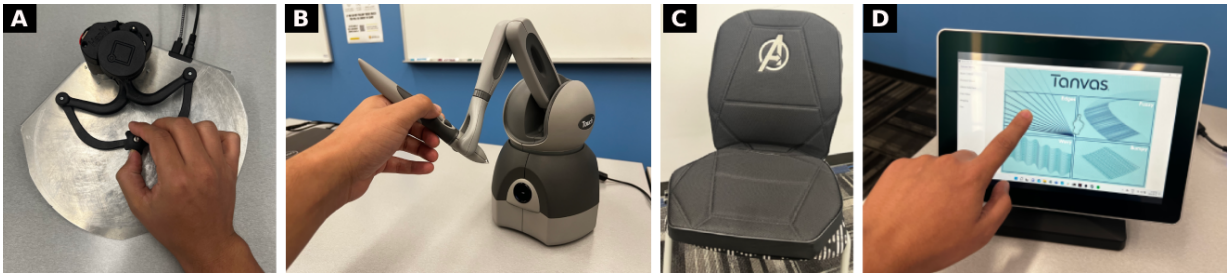


Figure 3.3: Haptic devices used in Haptic Mini-Tour A) Haply 2diy: a low-cost two degrees of freedom force feedback device, B) 3D Systems Touch: a three degree of freedom force feedback device which allows users to feel virtual objects in a 3D environment, C) Avengers Vybe Haptic Gaming Chair: a vibrotactile chair that provides tactile sensation to users while playing games, D) Tanvas: a surface haptic device that can create different textures on the screen.

and-play systems to help users to help them come up with ideas, rapidly explore different sensations, and prototype how haptics could be used in the stories. More details about the Tickle Trunk is available in the appendix subsection A.1.1

3.3.2 Imagine

Haptics is not always about replication of how people perceive touch in the real world but can also be about how creativity and imagination could be infused with touch sensation [258]. In FPI, after supporting the feeling of haptics in context and playing with potential modalities, a facilitator needs to elicit the potential design decisions from participants, enabling them to imagine what haptics will be for their use case.

To support the Imagine step, we developed a set of Worksheets to enhance both verbal and written communication from the storytellers. Outcomes from these Worksheets are then used to construct prototypes in the next stage of the design iteration. As the initial

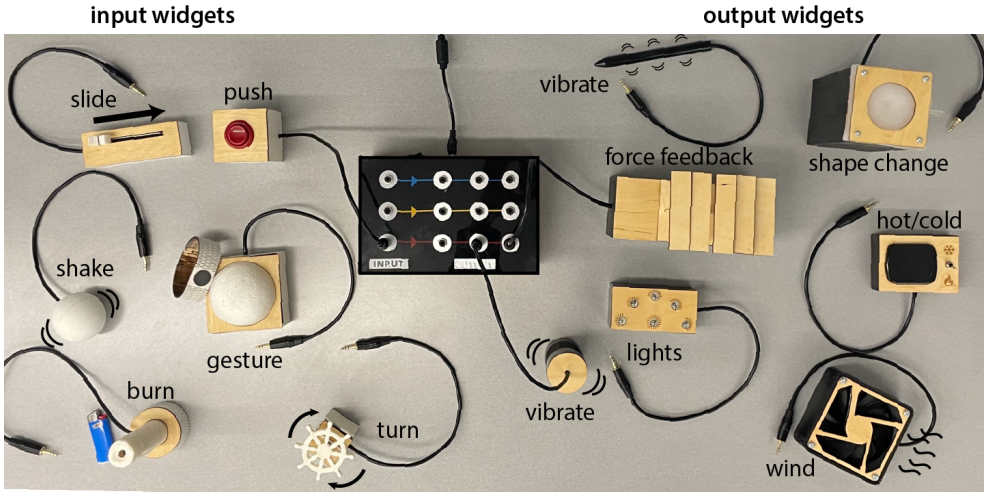


Figure 3.4: Tickle Trunk: a plug and play device to show different haptic modalities in forms of inputs and outputs. When someone manipulates an input widget, e.g., shaking the ball, the mapped output widget activates. A single input widget can be mapped to multiple output modalities, and can modulate the intensity of the output widget. For example, the gesture recognition input can activate the force feedback and shape change output widgets when connected in the same channel.

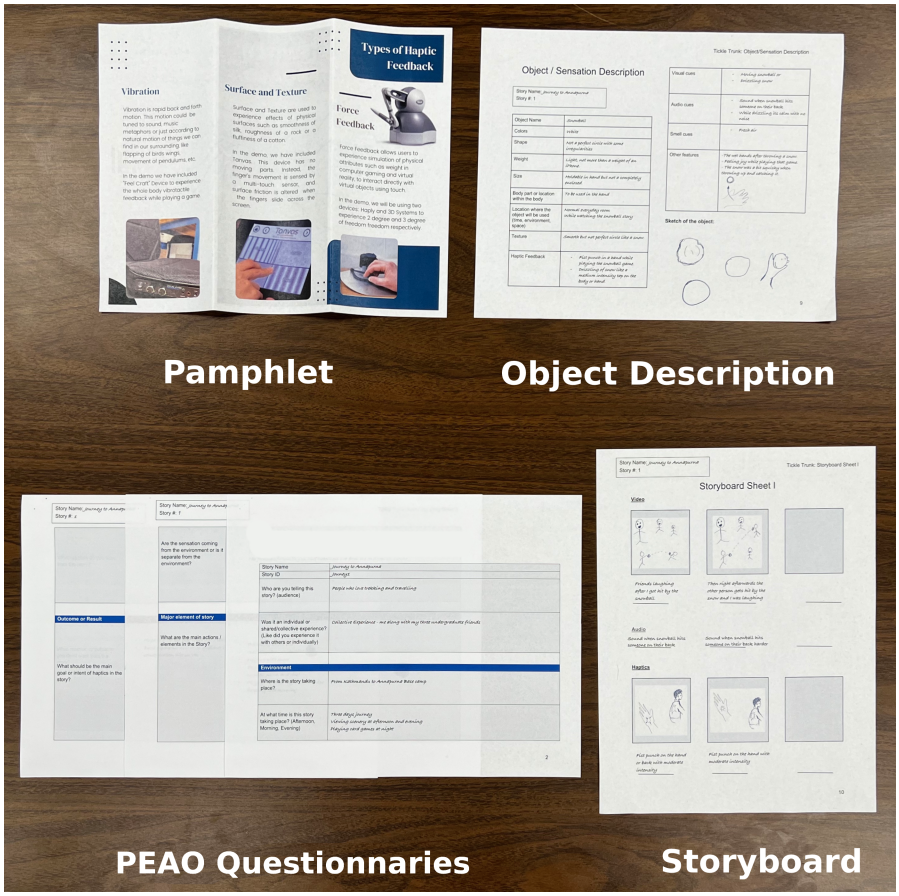


Figure 3.5: Worksheet consisting of a) PEAO (People, Environment, Action and Outcomes) Questionnaire consists of questions related to different elements of the story b) Object Description sheet consists of questions related to haptic object/device storytellers want to use to provide haptic feedback c) Storyboard helps to create visual representation of the how the haptic/object will look like in action d) Pamphlet provides brief details of the devices from Haptic Mini-Tour and input/output widgets from Tickle Truck to help participants recollect their memories.

phase of the brainstorming process, the Imagine step facilitates early data gathering. This not only empowers storytellers with creative control over their content but also validates the requirements more efficiently and reduces the time commitment required from storytellers involved in the design project.

Asking the right questions and creating proper documentation plays an important part in the design thinking and brainstorming process [229, 20, 76], and is especially important when helping people new to haptic technology [482]. To facilitate this process in the Imagine step we have created our custom-developed Worksheet shown in Figure 3.5 (also available in subsection A.1.2).

Sections of the Worksheet

The Worksheet is divided into four sections: PEAO questions, Object description, and Haptic Storyboard.

- *People, Environment, Action and Outcome (PEAO) Questionnaires (Figure 3.5)*: Stories are crafted based on key elements such as characters, settings, plot, and resolutions [199, 441]. These fundamental components serve as the backbone of any narrative. The PEAO questionnaire sheet provides a systematic set of questions related to the characters (people), setting (environment), plot (actions), and resolutions (outcomes) of a story. This strategic approach aids storytellers in determining the most effective questions for **"where"** haptics can be implemented within their narratives.

- *Object Description (Figure 3.5):*

Story Elements	Questions
People	– Who is telling the story – Was it an individual or shared/collective experience? – Who else is there in the story and how would they influence this story?
Environment	– Where is the story taking place? – At what time is this story taking place? (Afternoon, Morning, Evening) – What are there in the surrounding environment? Which is important to this story? – Is the sensation coming from the environment or is it separate from the environment?
Actions	– What are the main actions in the story? – How could you relate the above action with haptics or sense of touch? (If it helps, please use metaphors and examples to explain your story. It doesn't have to be literal; it can be emotional as well). Please define the body part for the sensation if possible. – Can you describe the above actions in five words? Could be an expressive word that provides information on what the narrator or actor is feeling at the moment (E.g.: warm, cold, far, exciting)
Outcome	– What should be the main goal or intent of haptics in the story? – What reaction do you want from the story? – What reaction or outcome you don't want from the story?

Table 3.3: Questions included in PEAO Questionnaire

The Object Description sheet includes a series of questions related to the attributes of the object or prototype intended for haptic feedback. The questions are derived considering the user experience and multimodal aspect of haptic technology [428, 624, 224, 482]. It covers aspects like size, shape, and feedback type, among others. This sheet is designed to help storytellers describe the object(s), device(s), or feedback(s) they wish to incorporate into their story for a more interactive audience experience. Essentially, this sheet serves as a tool to clarify **"what"** haptic objects or devices storytellers wish to incorporate into their stories. The questions listed in this sheet regarding the haptic device to be created are as follows:

  - What are the shape, weight, size, and color of the object?
  - To which body part will the device be attached?
  - What is the texture of the device?
  - What type of active or passive haptic feedback do you want from the object?
  - Do you have a visual description of the object? Can you sketch a rough layout of the object?
  - Do you want the device to have any audio or smell cues?
  - Are there any additional features you would like to include in the device?

.

- *Haptic Storyboard (Figure 3.6)*:

  The Haptic Storyboard is divided into three sections, each designed to graphically

represent the visual, audio, and haptic elements of a story, thereby visually representing the multimodal aspects of haptic design in relation to the story plot. This documentation tool was developed to assist storytellers in visually conceptualizing how haptic devices or objects can be integrated into different scenes. The storyboard takes into account the multi-modal aspect of haptic design, allowing storytellers to understand **"how"** to incorporate haptics into their narratives.

The pamphlet shown in Figure 3.5 functions as a supplemental guide for participants. It has a list of haptic terminologies and devices featured in the Haptic Mini-Tour, along with the input-output modalities from the Tickle Trunk. This pamphlet was designed to assist non-haptician storytellers in recalling the haptic feedback and devices they interacted with during the Feel and Play steps.

All the questions in the Worksheet are optional; participants can fill the Worksheet as they deem fit. The haptician should facilitate this session and include their own specific questions which could help them understand the participant's expectations.

3.4 Methodology

A workshop and a lab study was conducted to evaluated the use of FPI process with two different groups:

- Group 1 (Workshop): Collaborators and experts from our co-design team
- Group 2 (Lab Study): Expert designers and storytellers (external to our team)

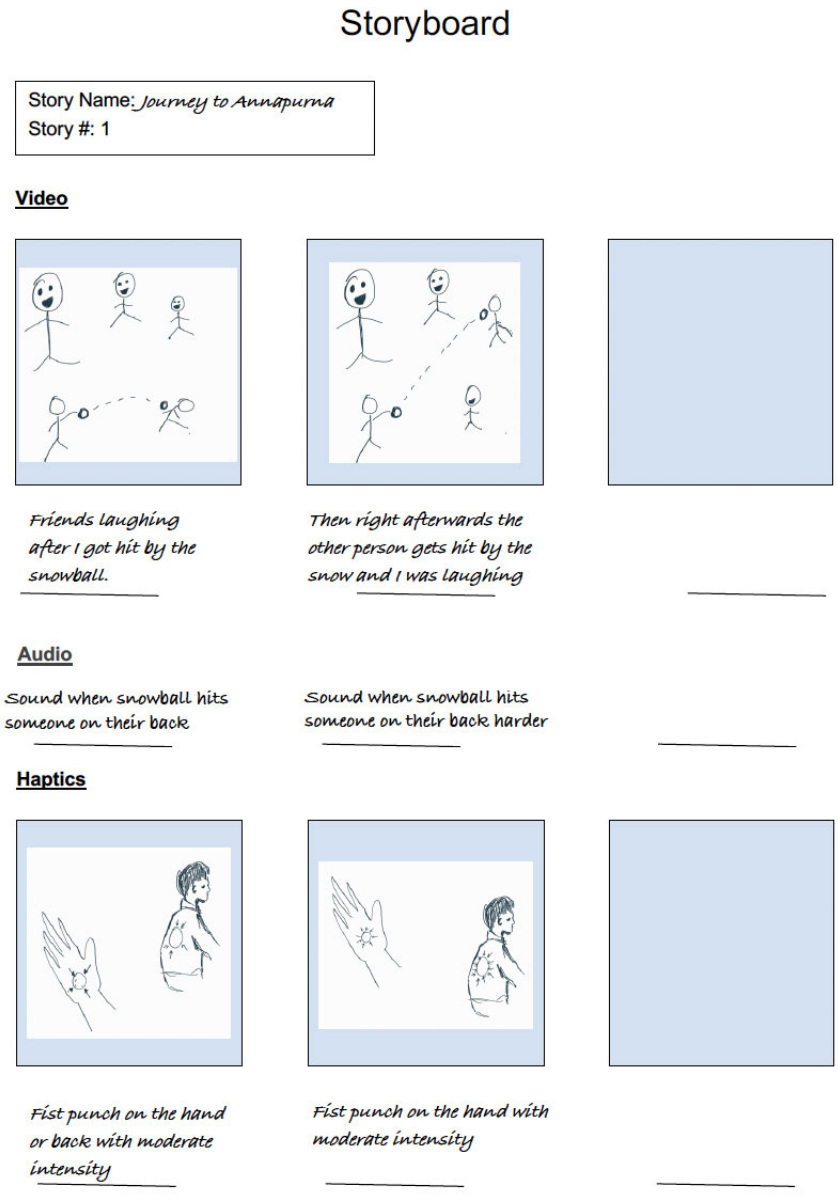


Figure 3.6: Haptic Storyboard included in the Worksheet helps to create visual representation of the how the prototype/object will look like in action

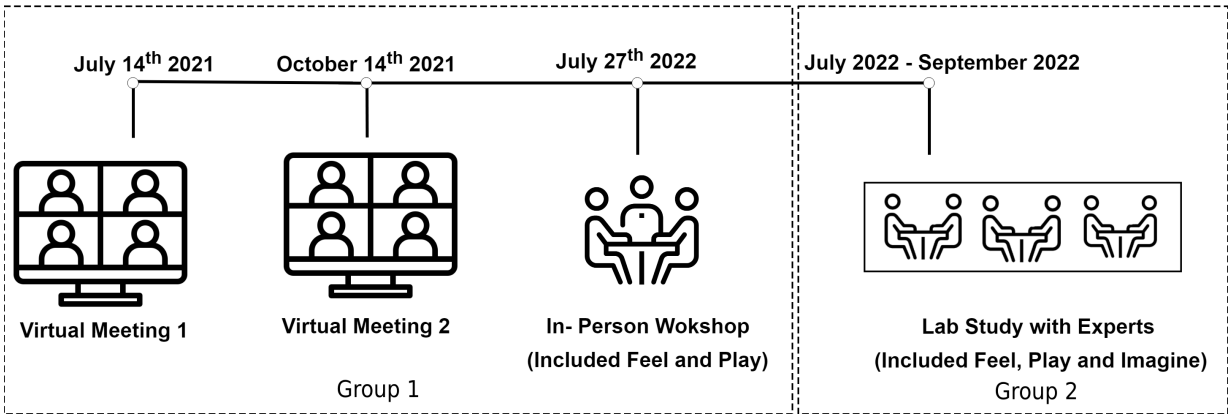


Figure 3.7: FPI development timeline

3.4.1 Workshop with co-design Team

The primary objective of the workshop was to gather requirements from our collaborators to create a haptic device that could be used as a museum piece for the DOHR project. The workshop included five collaborators from the co-design project, four members from the haptics team, and two other participants with a background in restorative justice (see Figure 3.8). Previously, due to the COVID-19 pandemic, the haptics team had met with the collaborators several times online to build a relationship, understand the project's mission, and introduce haptic technology to the team. However, verbal explanation and visual representation of haptic technology made it difficult for our collaborators to understand the technology and create requirements for the haptic device to be included in the museum. As circumstances started to improve with the pandemic, our first in-person workshop was planned. This work was conducted entirely within our research team, with community co-designers participating as active team members throughout. The process was exclusively collaborative and consistent following restorative-justice principles. Accordingly, a sepa-

rate institutional ethics review was not sought for this design phase because it did not constitute human participants research beyond the research team.

In the workshop session, we used the Feel and Play step to introduce the audience to haptics, as shown in Figure 3.9, and initiated an open-ended discussion to understand the requirements for the museum piece. In the FP step, participants were given an explanation and the opportunity to try different haptic devices (i.e., Haptic Minitour and Tickle Trunk). This approach assisted in brainstorming ideas and creating requirements for the inclusion of haptics in the stories. Our collaborators had already conducted a comprehensive discussion of the DOHR stories during the development of the VR experience for the project, and haptic teams were provided with resources to familiarize themselves with the content of the DOHR stories. Therefore, the Worksheet was not used in the Imagine step since most of the questions were intended to emerge organically from the discussion following the process used in the VR experience design. Instead, the sharing circle filled the need of the Imagine phase.

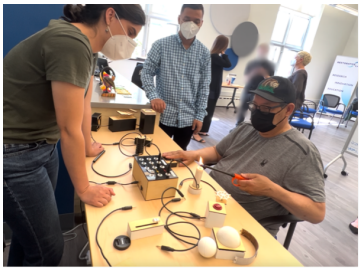
The discussion touched on topics related to the benefits and objectives of using haptics, how to use haptics in stories, and important details to consider while incorporating haptics in stories of marginalized groups, especially institutionalized racism.



Figure 3.8: Restorative justice sharing circle in the discussion session shows the Imagine step used for the workshop.



Workshop participant using the Vybe haptic chair from the haptic Mini-Tour.



Workshop participant using the Tickle Trunk input and output widgets.

Figure 3.9: Co-design project team using Feel and Play process in the in-person Workshop

3.4.2 Lab Study

The use of a sharing circle in the workshop was important given the restorative process, and productive because the DOHR team was established and had deep understanding of their needs and goals. However, in other cases, this structure might not exist. The Worksheet

(subsection 3.3.2) fills this need in other contexts. In the Lab study, we used the same FP setup for the introduction of haptics, but employed the Worksheet for structured imagination. We conducted a qualitative study consisting of semi-structured interviews and survey questionnaires with ten non-haptician storytellers from backgrounds in Storytelling, Art, Gaming, and User Experience (UX) Design. The primary purpose of the study was to evaluate the usefulness of the FPI process and its toolkit, and to gain a deeper understanding of how haptic brainstorming and discussion work. Accordingly, the two studies provide complementary evidence: the workshop grounds FPI in a real restorative-storytelling context, and the lab study systematically tests its creative and usability outcomes.

We conducted an in-person study in a large lab space (Figure 3.1). Participants were provided with an instruction letter at least a day before the study, detailing the study and asking them to come prepared for the study session with their own short story that they might want to use with haptics. Participants were encouraged to use their original stories, children's stories, or stories from their personal experiences.

On the day of the study, the pre-session began with participants being greeted by the haptician, who then provided a brief introduction to the study and the steps that would be followed throughout the study. Participants then read and completed consent forms and demographic questionnaires. This study received ethics clearance from the University of Waterloo Research Ethics Board (ORE 44482). The approved consent form and participant feedback letter, along with the full survey instruments used (USE and Creativity Support Index), are provided in Appendix B. I have included the exact materials (consent form, feedback letter, and the exported Qualtrics questionnaires) so readers can audit the protocol and reuse the measures. As shown in Figure 3.11, the participants went through the

three steps of the FPI process: the Feel and Play step, where participants tried the Haptic Mini-Tour and Trickle Trunk, and the Imagination step, where participants were given a quiet space to go through the questions in the Worksheet and write their own stories.

At the end, participants took part in a 10-20 minute semi-structured interview and completed survey questionnaires. The questionnaire was used for a usability questionnaire to evaluate USE metrics (usefulness, ease of use, ease of learning, and satisfaction) [340], and the Creativity Support Index (CSI) questionnaire, which is used to measure the ability of the tool to support users' engagement in creative works [103]. The study took approximately 90 minutes, and the participants were given 20 CAD in appreciation of their time. Photographs, audio, and video recordings were taken throughout the study with the permission of the participants to later analyze their feedback and interaction with the devices.

We recruited ten participants (self-reported genders: 1 female, 8 male, 1 non-binary) with ages between 21-34. Participants were recruited using our professional networks, word of mouth, and by reaching out to theatres and art institutions. Participants were adults with background in gaming, design, UX, and visual arts.

Here we have described each participant in terms of their highest qualification along with their professional and educational experience.

- **P1** (over 10 years of experience in art, designing and storytelling, Undergrad) held experience in making experimental alternative controller games in collaboration with hardware hackers.

- **P2** (5 years of experience in storytelling, Masters) has experience in narrative designer and games studies.

- **P3** (7 years of experience in designing and storytelling, Doctorate) held experience in designing games and gameful systems for educational purposes.
- **P4** (7 years of experience in designing, art and storytelling, Doctorate) is a writer, designer, and artist with primary interest in comic books.
- **P5** (5 years of experience in designing, Undergrad) is a UX designer with experience in mobile and industrial design.
- **P6** (3 years of experience in designing, art and storytelling, Doctorate) held experience in designing and video game storytelling as part of dissertation work.
- **P7** (4 years of experience in designing and storytelling, Masters) is a UX designer with experience in VR and games.
- **P8** (3 years of experience in art, Undergrad) held experience in digital arts and multimedia storytelling.
- **P9** (5 years of experience in designing, art, and Storytelling, Masters) held experience in theatre, music, and writing.
- **P10** (5 years of experience in storytelling, Masters) is a mechatronics engineer with music and theatre experience.

3.5 Resulting Themes

We employed reflexive thematic analysis [74, 462, 384] to examine data collected from discussions with the co-design team, semi-structured interviews, video recordings, and work-

sheets completed by participants in the lab study. Two researchers (the first and second authors) transcribed and analyzed the data using reflexive thematic analysis. For the *lab study*, we captured a total of 185minutes of video and audio, comprising participant interaction, Worksheet talk-throughs, and post-task interviews; this corpus formed the primary dataset for coding. Written notes from the earlier DOHR workshop were consulted only as sensitising material and were not included in the 185-minute coding corpus. The analysis was open-ended, allowing themes to naturally emerge from the data. We started by carefully reviewing the transcripts, notes taken during the study, and video recordings. This helped us understand what participants said, as well as their body language, tone, and facial expressions.

The first author created initial codes by noting repeated behaviors and patterns in each participant's responses. These codes were then grouped into broader themes that captured the main ideas across participants' words, actions, and reactions. We refined and revised the themes several times, using feedback from the research team, to make sure they clearly represented the data. Each theme was defined and given a meaningful title. In the end, we wrote a report linking the themes to the research questions and key findings.

3.5.1 Learning about haptics through experience: physical interaction was essential

The importance of physical interaction in comprehending haptic technology was a recurring theme in our research. Despite participants engaging in online discussions about haptic technology for over a year, it was only during the in-person workshop that collaborators

fully understood the materiality of haptics for storytelling. As one collaborator stated, *"using physical things provided good examples"* (P1), illustrating the importance of concrete experiences in understanding abstract concepts. Another participant emphasized the role of physical engagement, stating, *"you get the feel of riding on the horse, the fall and the explosion, all that, it creates a new body experience"* (N1).

In the lab study, participants similarly gained a deeper understanding of haptic technology through direct experience. For instance, participant P3 initially asked about the differences between two vibration outputs provided by the Tickle Trunk without any physical experience. The haptic expert explained that one vibration was stronger and the other lighter; experiencing these outputs firsthand was essential for connecting descriptive language to physical sensation. P3 recognized this connection, remarking, *"ooh, I get what you mean by strong vibration."*. The variety of sensations participants encountered allowed them to expand their repertoire of haptic modalities. Participant P7, for example, applied multiple effects from the Haptic Minitour session into a narrative depicting a protagonist changing a car tire in a rainstorm. P7 explained, *"I used x, y, and z-axis [in 3D Systems] to open the nuts with the tire iron, Texture [in Tanvas] to represent rubber material, and Vibration [in Tickle Truck] to indicate that the car was still running"* (P7). This illustrates how direct experience with haptic sensations enabled participants to integrate these modalities effectively into their storytelling.

The demos expanded participants' understanding of "haptics" beyond vibration, introducing them to additional modalities such as texture, shape-change, and temperature. Both workshop collaborators and lab study participants expressed surprise at discovering these broader possibilities. One collaborator remarked, *"there are so many variations"* (N1),

while another noted, *"didn't know texture was part of haptic"* (P1). Certain modalities, such as 3-DOF force feedback, offered entirely new experiences. For example, participant P2 was notably impressed by the capabilities of the 3D Systems Touch device, stating, *"I like the pen tool—I didn't know it could do that"* (N2). Participants P3, P4, and P7 recognized differences in fidelity and interactivity between devices, specifically comparing the Haply and the 3D Systems Touch. Participant P4 observed, *"in [Haply], the control was very limited; [3D Systems Touch] provides a real-world sense of force in 3D space"* (P4), while P7 emphasized, *"[3D Systems Touch] gives the audience the genuine feeling of holding and moving an actual tool in space rather than that [Haply]"* (P7).

Participants also showed interest in combining multisensory experiences, reflecting increased curiosity and broader conceptualization of haptic possibilities. Questions such as *"can I use all these effects together?"* (P3) and comments like *"it would be great to combine effects (pointing to input and output modules in the Tickle Trunk)"* (C5) indicated a shift from initial exploration to advanced integration. Participant explorations, such as *"I want to try heat and vibration together"* (P9), suggest progression from basic comprehension to envisioning complex multisensory narratives.

3.5.2 Interactivity invites curiosity: participants entered a "euphoric possibility space"

In-person haptic demos not only enhanced our collaborators' and participants' understanding but were also *"great for sparking creativity"* (P10). They entered a *"euphoric possibility space"* (N1), where they began to brainstorm new ideas for using haptic technology in sto-

rytelling: *"I wonder if warm or cold could be used in the story"* (P4). Curiosity extended to the underlying technology: *"how is this device doing this? (pointing to Tanvas) is this haptics?"* (C6). The devices in the Introduction step were described using words such as: *"therapeutic", "intuitive", "playful", "curiousness", "learn through play", "unexpected", "evocative", "approachable", "feels like you are in the picture", "enjoyed witnessing the rain", and "engaging."*

Interaction, both with other people and with the devices, fostered an enthusiastic atmosphere. In our workshop, collaborators eagerly encouraged others to try out the various setups, with exclamations like *"feel the bubble!"*, *"light the candle!"* and *"did you feel the rain?"* One particularly intriguing suggestion was to combine the action of lighting a candle with the sensation of cold, a concept that piqued everyone's curiosity and led to most participants trying out this unexpected pairing of input and output. During the lab study, participants actively interacted with the devices to conceptualize potential uses for the feedback: *"falling off a boat could be holding something like a ball (from Tickle Trunk) and its tipping"* (P2), *"I am thinking of using all major actions such as with door knobs, sitting down, touching bugs, feeling broken glass and more."* (P9).

3.5.3 Assessing value: haptics supported design goals through emotion and realism

As introduction shifted to imagining, both collaborators and participants were able to initiate design decisions during the discussion session of the workshop and while using the Worksheet in the lab study. The focus varied depending on the story and device participants

were planning to use in the story, but both parties were able to make design decisions to support their storytelling objectives.

For instance, N2 created a story where users could experience environmental elements through haptic effects, such as *"wind blowing, walking sensations, foot movements, stepping on leaves, and the buzz of water. Similarly, P7 wanted users to feel immersed in the moment by sensing textures, noting,* "[Tanvas] can help users feel the texture of the injured bird's feathers in the story" *(P7). In contrast to these environmental approaches, C4 focused on emotional expression through symbolic symbols enhanced by using haptics:* "the candle growing brighter and stronger [to express resilience in the story]" *(C4)."* (N2)

This last focus, emotional expression, was front and center in both in the workshop and lab study. Participants identified a range of emotions potentially evoked by haptic interactions. When engaging with the haptic devices introduced in the initial step of the process, participants and collaborators reported a diverse array of emotional responses, using words like *"anxious", "therapeutic", "enjoy", "fun", "joy", "excitement", "evocative", "fear", "guilt", "pleasure", "curiosity", "achievement", "empathy".*The term "guilt" surfaced when a DOHR narrator considered how intense, body-felt feedback could affect future museum visitors: experiencing the vibrations, force cues, or temperature changes that accompany scenes of institutional harm *might make visitors feel guilty* by confronting them with a visceral sense of the injustices portrayed. Thus, "guilt" was raised as an ethical design concern—anticipating a visitor response—rather than as an emotion the narrator personally experienced during our study.

However, the workshop and the lab study demonstrated conflicting views on how emotion might interact with realism. In the workshop, participants underscored the need for

careful consideration of the emotional aspects of haptics, particularly in conjunction with DOHR stories that often dealt with sensitive subjects. There was a shared concern that haptic interactions could amplify realism to a potentially distressing or harmful extent, especially in narratives centered around trauma. C5 expressed their concern about the potential misuse of haptic technology, stating, *"the effect felt like it was tampering like it was manipulating my emotional response in a way that didn't feel natural."* C5 further elaborated on their concerns by saying, *"I had DOHR stories in mind, and I thought about how this (haptics) could be misused in terms of enhancing an experience, and we could do harm. We've been very deliberate about not wanting people to experience the pain that the they (narrators) have experienced in these stories."*

In contrast, participants from the lab study used haptics to simulate realism across devices: *"I want to use Haptic Gaming Chair to simulate walking on snow"* (P4), *"use 3D Systems Touch to simulate grabbing a live animal"* (P3), *"use Tickle Trunk to simulate bird's body temperature and respiratory movement"* (P7). The findings suggest that the desired emotional outcome from haptic feedback may vary depending on the narrative context.

Ultimately, collaborators and participants were able to assess the potential value of haptic technology in supporting their storytelling goals and making their own design decisions. Our workshop participants noted the potential value of this technology in storytelling: *"this helps me in listening"* (C4); *"add vibrations, or wind or even textures, if that is even possible, those would be things I'd like to see in the stories"* (N2). They suggested that haptic interactions could significantly influence the emotional tone of a narrative, with the potential to either enhance or detract from the intended emotional impact *"I guess the*

emotions I felt at various times were excitement but I felt other emotions as well." (C3) and *"there was a combination of emotional responses"* (N1). Meanwhile, in the lab study, participants echoed the importance of haptics in storytelling, emphasizing its potential to enhance realism while designing haptics for their stories: *"when the audience falls into the water, the suit will vibrate to simulate shivering"* (P3), *"a bit of warmth to the chair as heat to create a feeling of safety in the story"* (P7), *"I want to include a lack of control to freak people out and induce fear"* (P2).

3.5.4 Structured discussion helped build priorities

The imagination phase of the workshop was shaped by a structured discussion, grounded in a restorative process and pre-established design practices. In alignment with this, we used a sharing circle to reflect and discuss the next steps, guided by the expert VR designer who had led the DOHR VR design.

As the DOHR project deals with sensitive and traumatic subjects, haptic design had to carefully manage the emotional side of how narrators' stories were interpreted. Emotional responses were a central topic of discussion among collaborators, with important questions raised such as *"How does haptics interact with the intended emotion versus the actual emotion felt by the audience?"* (C4) and *"Could engaging with emotion cause harm?"* (C5). One participant reflected on their own experience, sharing, *"I had an anxiety response [while using the heartbeat vibration]... I don't want someone to be able to make my heart race like that,"* (C4) highlighting the potential risks of emotional manipulation through haptics. However, the conversation gradually shifted toward a more hopeful direction, focusing on

how to intentionally harness emotion to enhance learning. As another participant asked, *"How can we prioritize emotion to enhance learning?"* (C3).

Through this structured dialogue, the group identified that haptic interactions should foster feelings of connection, groundedness, and safety rather than distress or overwhelm. As one collaborator emphasized, *"We want them to feel grounded and present,"* (C7) while another stressed the importance of tangible engagement, *"Having something tangible in front of you that gives some sort of force feedback would add so much to a more real-life immersive experience."* (N2). This attention to emotional tone led the team to favor haptic designs that embraced positive emotions and strengthened participants' connection to the stories. Experiencing different haptic prototypes reinforced the value of tangible objects. For example, N1 proposed the use of the Sankofa, stating, *"You hold the Sankofa [a symbolic statue from the West African community and important to the Narrators] at the beginning for your onboarding to the VR, to understand the symbolism right from the start,"* (N1) while *"We could do something with the candle before or during the VR experience, such as lighting it, to symbolize entering the story space."* (C5).

The structured reflection also surfaced several key guidelines and desired outcomes for haptic design. Collaborators emphasized that haptics should enhance learning and accessibility. As one participant noted, *"Haptics could help make the learning stick and extend the conversation afterwards,"* (C7) emphasizing its potential to deepen reflection and memory. Others reflected on the broader educational value of haptics: *"So many people could use this technology to learn and educate at many different levels — in essence, educational credit that therapeutically, the sky's the limit."* (C4). Accessibility was equally foregrounded, with collaborators highlighting the importance of reaching users who might not communicate

exclusively through visual means, as captured by *"People who might not communicate exclusively through visual means — there's a lot of opportunities there,"* (C6) and reinforced by *"We might use haptics to provide experiences that aren't available to VR participants who aren't seeing or hearing fully."* (C7).

By the end of the workshop, the structured discussions had helped build a clear set of priorities to guide future design directions. Given the scale of the project—a pre-existing, multi-person, multi-year initiative deeply rooted in a restorative process and educational partnerships—the workshop did not produce a concrete design. Instead, it cultivated a nuanced understanding of the broader ideas, values, and priorities that our collaborators and community partners hoped to see realized in the evolving work.

3.5.5 Structured Worksheets Helped Shape Haptic Story Ideas and Concrete Plans

In the lab study, the Worksheet helped structure discussion for efficient identification of potential design decisions for smaller-scope projects. Participants appreciated the well-structured nature of the questions, which guided their thought process and helped them to explore various possibilities: *"questions were pretty well done, helped to guide the experience well"* (P2), *"Worksheet got me thinking about the possibilities"* (P1), *"it (Worksheet) helped me to come up with ideas"* (P4). The questions in the Worksheet encouraged participants to view the story from multiple perspectives, including environment, people, and objects of interaction as shown in Table 3.4.

This structured approach not only helped to clearly define and document their ideas

but also facilitated the incorporation of haptics into their imagined stories. Participants appreciated the quick ideation and well-structured discussion facilitated by the Worksheet: *"questions helped to come up with ideas quickly"* (P2), *"questions were well structured"* (P7), *"loved the progress of the question gets you an idea of what's going on"* (P9). Each question seemed useful: *"I did not find any redundancy across this and I think the questions were good"* (P6).

Participants were able to work through the autonomously. Despite the diversity in participant , required no further assistance after a brief introduction to the . Participants then *"I want a Haptic Gaming Chair effect to simulate walking on snow"* (P1), *"used a 3D Systems Touch to simulate grabbing a live animal"* (P3), *"used haptics in all major actions such as door knobs, sitting down, bugs, broken glass, etc"* (P5), *"want the sense of a warm environment"* (P8).

3.5.6 Multimodal communication: use of gesture and body movement to convey design requirements

Across both the workshop and the lab study, to clarify . Figure 3.10 showcases .

For example, C5 articulated

P2 employed a slow, pendulum-like body movement to simulate the sensation of imbalance, intending to evoke the experience of drowning in water; P4 mimicked the act of gripping a steering wheel to illustrate the driving experience; P9 demonstrated how an audience member might hold and gently shake a guitar to assess its weight and texture during a purchase; and P10 enacted the action of swinging a sword in a fantasy narrative.

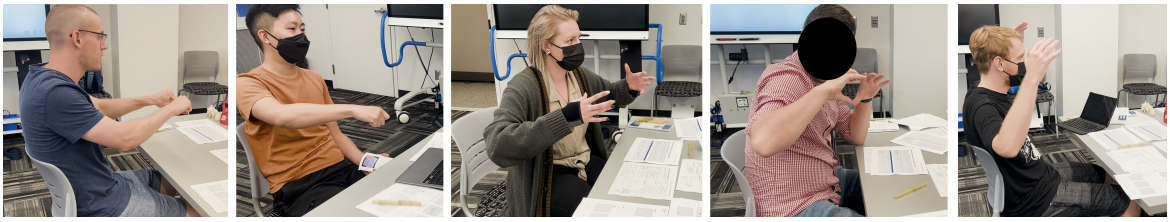


Figure 3.10: (Participant faces hidden for anonymity.)



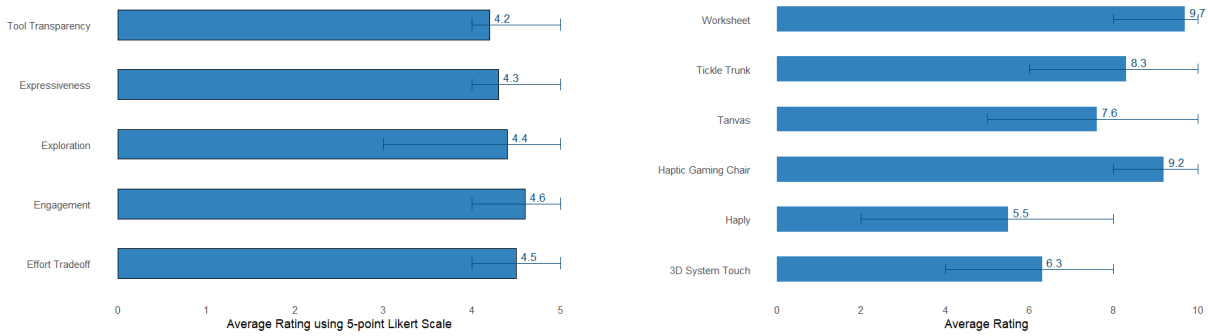
Figure 3.11: Participants using different supporting tools from the FPI process. A and B show participants in the Feel step, C shows a participant in the Play step interacting with The Tickle Trunk and D shows a participant writing on a Worksheet in the Imagine step.

Collectively, . .

3.6 Results from Questionnaires

Our 10 lab study participants created 10 unique stories from various genres, including fantasy, sci-fi, real-life experiences, children's tales, and embellished real-life narratives. A brief overview of some of these stories is presented in Table 3.4.

Overall, participants rated the FPI process highly on the CSI Index (mean 4.4, sd 0.57) as shown in Figure 3.12a. Ratings were generally high for all CSI components, including Tool Transparency (mean 4.2, sd 0.75), Expressiveness (mean 4.3, sd 0.46), Exploration



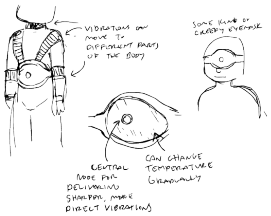
(a) CSI Index for the FPI process.

(b) Usefulness of haptic tools

Figure 3.12: Participant feedback summary. a) Participants ratings collected using CSI index showed higher score for all factors. b) Participants' perceived usefulness of tools were rated highly for Worksheet and Haptic Gaming Chair.

(mean 4.4, sd 0.49), Engagement (mean 4.6, sd 0.49) and Effort Tradeoff (mean 4.5, sd 0.5). Further, all three components (Haptic Mini Tour, Tickle Trunk, and Worksheets) were rated highly using USE Usability Metrics (Figure 3.13).

When rating FPI components for usefulness (on a scale of 0-10), participants most useful tools included Worksheet (mean 9.7, sd 0.64), Haptic Gaming Chair (mean 9.2, sd 0.87), Tickle Trunk (mean 8.3, sd 1.49), and Tanvas (mean 7.60, sd 1.5)(Figure 3.12b). However, on average force-feedback devices Haply (mean 5.5, sd 1.75) and 3D Systems Touch (mean 6.30, sd 1.19) were rated as less useful. Participant comments suggested that these devices were framed as tools rather than facilitators of an embodied experience: *"imagining these devices (pointing to 3D Systems Touch and Haply) was difficult in the context of my story"* (P8), *"I see Haply as a tool to control settings"* (P2) and *"I'm not sure how to incorporate Haply into my story"* (P9). This could be influenced by the selected demos for the force feedback devices, which consisted of like Jenga and Maze Game.



Title Pilgrimage of Worms

Brief Description
Science Fiction and Body Horror story where main characters starship is enslaved and is being controlled by a parasitic worm.

Haptic Device

Body location / Appearance
Arm band, belt, jacket and eye mask. Most actions take place in the belly area and some maybe in neck and face.

Feedback
Damp strait jacket Texture. Worms writhing : uneven vibrations in and around the belly. Worms commanding: strong forceful push or tightening sensation Flying through space: cold sensation Plasma burst: heat building in belly, travelling through mouth.



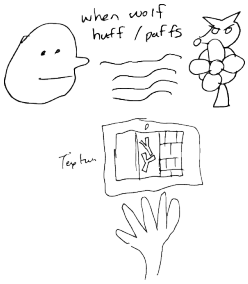
Title Boat Ride Gone Wrong

Brief Description
Embellished story based on real experience where narrators boat tips over in a river.

Haptic Device

Body location / Appearance
Arm or Leg Bands, Gloves, Backpack or Jacket.

Feedback
Freezing temperature on back and front of hand and body, rumbling on the back and legs to feel the waves and effects of water, feel the velocity and restriction of moving under the water. Wet and smooth texture of water.



Title Three Little Pigs

Brief Description
Children story where a big bad wolf blows down the pig's house made of straw and sticks but is not able to destroy the house made of bricks.

Haptic Device

Body location / Appearance
Texture pad and wind generating machine

Feedback
Fan breeze and shaking chair as the houses fall. Different texture houses. Feeling of heat of chimney from the fan or jacket. Small vibration while running.

Table 3.4: Summary of haptic feedback and story descriptions for three randomly selected participant objects (from a total of ten).

Topics	**In-Person Workshop**	**Lab Study with Experts**
Structure:	Introduction with Feel and Play, then open-ended discussion structured as a sharing circle.	Introduction with Feel and Play, then structured discussion with provided Worksheets.
Discussion about:	Haptics and its possibilities and guidlines in the story.	Results from the Worksheet questionnaire.
Time spent:	A full-day in-person meeting.	A 90 minute (approx.) in-person session.
Outcome:	Participants understood the concept of haptics; discussion mostly surrounded around broad discussion of application of haptics and it usefulness in the story.	Participants understood the concept of haptics, and there was clear documentation and visualization of where to use haptic devices or tools in the story, supported by sketches.

Table 3.5: The table gives a quick summary of two formats used to introduce and imagine the design requirements of haptic devices desired by the storytellers.

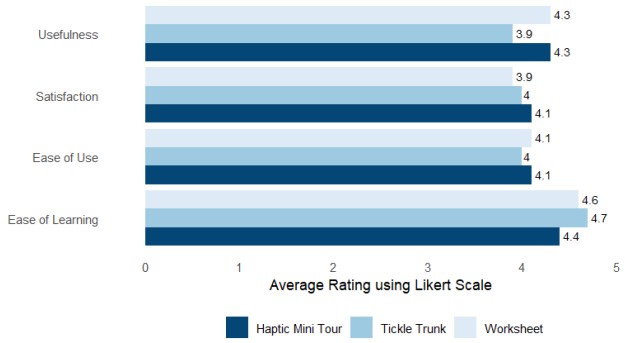


Figure 3.13: USE Usability Metrics for FPI toolkits. Participants rated FPI tools highly on all factors.

3.7 Discussion

Overall, we found the FPI process was a useful way to structure introduction and shared imagination of haptic technology. In the workshop, the FPI process was used to explore the use of haptics in challenging VR stories and led to follow-up work in our co-design project. In the lab study, the FPI process was employed to assess its effectiveness with storytellers in designing haptics for various genres of stories, including fantasy, sci-fi, real experiences, children's narratives, and embellished real stories.

Our takeaways include the importance of hands-on experiences with haptics, value of following a structured process when introducing and imagining haptics, the diversity of ways that people express themselves when talking about haptics, and the usefulness of having a wide number of examples. We also note outcomes about using haptics carefully, and not over-employing the modality.

3.7.1 Hands-on Exploration: Provide hands-on, playful haptic experiences to help people understand haptics

The physical interaction with haptic devices plays an important role in understanding the concept of haptics [111, 346]. The use of devices such as the Haptic Mini-Tour and Tickle Trunk provided a practical understanding of how the technology operated and the sensations it can produce (subsection 3.5.1). This practical knowledge was instrumental for storytellers during the imagination process as they drew upon their encounters with the Haptic Mini-Tour and Tickle Trunk when articulating the feedback they wished their audience to experience (subsection 3.5.5). The devices and haptic feedback examples were frequently referenced by participants to convey their desired haptic design requirements for their stories. This suggests that the inclusion of actual physical devices in the discussion fostered a more meaningful and in-depth conversation. This aligns with previous studies that have emphasized the role of experiential learning in enhancing comprehension of complex concepts [175, 173], and with hands-on physical feedback in education [208, 127]. Crucially, these findings reiterate a quality that is unique to haptics: learning is not merely cognitive but bodily and affective. Unlike visual or auditory demos, a vibration on the torso or heat on the palm gives an immediate, first-person glimpse of material constraints—latency, amplitude limits, skin location—that participants then carry into ideation.

We found that the FPI process not only provided this hands-on experience, it provided a fun, playful atmosphere. Our research participants expressed enjoyment in their hands-on interactions with the devices and experimentation. P1 noted that the availability of the tool served as a *"good conversation starter"*. The hands-on experience allowed

participants to explore different haptic sensations and their combinations, thereby gaining a practical understanding of the feelings of vibration, warmth, and texture generated by haptic devices. This experiential learning facilitated participants' comprehension of the terminologies used by hapticians. In our workshop, our collaborators described this as a "euphoric possibility space" (subsection 3.5.2). This finding is consistent with previous research that suggests a playful atmosphere promotes engagement, motivation, creativity, and innovation [574, 446]. Overall, what makes haptics distinct is its inherently embodied and affective nature—participants were not merely learning *about* haptics, but learning *through* the experience. The experience was not just informative but emotionally expressive, allowing participants to reason about emotions, textures, and interpersonal cues in non-verbal ways. This underscores how hands-on haptic experiences offer a uniquely situated form of knowledge-making that differs from other sensory modalities.

3.7.2 Structured Imagination: The structure of Feel-Play-Imagine supported design decisions

In both the workshop and lab study, the Introduction step was found to be a significant tool in promoting dialogue and ideation (subsection 3.5.1,subsection 3.5.2,). The integration of an Imagination step in the lab study further enhanced the efficacy of the brainstorming process, providing a more organized and productive structure subsection 3.5.5. This structure enabled participants to clearly express their design prerequisites and specific haptic feedback preferences in relation to their narratives (Table 3.4).

During the workshop, participants utilized elements from both the Haptic Mini-Tour

and the Tickle Trunk to support their points in the subsequent discussion subsection 3.5.2. The introduction phase of the FPI process was crucial for the discussion, where participants recounted their experiences with the haptic devices and the potential of incorporating the sensations they felt and devices they used into their narratives. Our collaborators were able to highlight practical outcomes desired from a haptic device, such as accessibility, emotional impact, and the creation of memorable experiences.

In the lab study, participants referred to the Mini-Tour and Tickle Trunk when expressing their preferences and dislikes, made decisions about the combinations of haptic modalities, and ultimately conveyed their design intentions using gestures and explaining what's written in the Worksheet (subsection 3.5.5, subsection 3.5.6). The entire process took approximately 90 minutes and received positive feedback and high ratings. Participants in the lab study specifically noted the importance of Worksheet in guiding their ideas (Figure 3.12a, Figure 3.12b).

While this structure was valuable in guiding both design activities, it might be flexibly adapted or reordered. Across both the workshop and lab study, we followed the intended sequence of Feel $\rightarrow$ Play $\rightarrow$ Imagine. P7 suggested starting with the Imagine step and allowing participants to move back and forth between steps, creating a more circular progression of the FPI process. However, aside from P7, all participants agreed with the linear progression of FPI, beginning with the Feel step using the Haptic Mini-Tour and ending with the Worksheet. In the future, we believe that the sequence could be adapted based on need and context. For instance, more flexibility could be incorporated during subsequent meetings in an iterative process, or large groups could be managed by having them attend different stations simultaneously. For now, we suggest the Feel$\longleftrightarrow$Play$\rightarrow$Imagine

as a default option.

3.7.3 Mixed Methods: Give options to express in different ways (i.e. writing, drawing or verbal discussion)

Providing diverse methods of communication - writing, drawing, and verbal discussion - proved to be an effective strategy in enabling storytellers to express their ideas (subsection 3.5.5). The use of body movements and hand gestures during verbal discussions further emphasized their thoughts (subsection 3.5.6). The positive feedback received from participants regarding the Worksheet proves the significance of a structured question set for discussion and brainstorming. This helped storytellers to articulate their desired requirements during the imagination process. The Pamphlet was also beneficial in reminding storytellers about the devices they used and haptic terminologies such as force-feedback, vibrotactile, texture, etc. Therefore, we recommend that hapticians should be flexible in utilizing various communication tools to fully understand storytellers' requirements.

The resources provided in the Worksheet for the imagination process were well-received by the participants (subsection 3.5.5, section 3.6). This aligns with previous research that emphasizes the importance of comprehensive documentation guidelines and the use of varied communication mediums during the design process for effective documentation [51, 356], and complements tools for flexible gestural expression, like the Sensual Evaluation Instrument [248], which could be used in the FPI process.

Our findings resonate with studies showing that early-stage visual or tangible scaffolds—such as as *Voodle*, which lets designers "sing" robot motions to explore affective

behaviour [359], Moussette [383]'s *Simple Haptics* sketches for quickly feeling out tactile ideas [383], and the broad family of card-and-game toolkits reviewed by Peters et al. [426]—help non-designers externalize tacit ideas and iterate rapidly. As P4 put it, "the questions made the whole story click together in my head," underscoring how the Worksheet's step-by-step prompts transformed vague concepts into a coherent narrative plan. Participants appreciated the structure and progression of the questions, which helped guide their thought process and stimulate their imagination Figure 3.12b. As a result, the use of diverse communication methods and structured questionnaires have been identified as key factors to imagine design requirements for a haptic device.

3.7.4 Examples: More examples are always handy

The FPI process during the in-person workshop and lab study showcased the application and functioning of various haptic devices and toolkits. For instance, we explained how wristbands, gloves, watches and other popular haptic technology simulate the sensation of touch. We also addressed any questions or concerns that emerged during these demonstrations. This hands-on approach helped participants grasp the potential of haptics and how it could be woven into their narratives.

However, some participants encountered difficulties due to their unfamiliarity with the tangible haptic toolkits. For example, one participant was uncertain about how a device that didn't simulate the act of grabbing would function within a story - *"devices did not simulate grabbing so I did not know how it will work"* (P5). Other participants questioned, *"how can something in arm and legs change the balance to get the feeling that you couldn't*

move that much" (P2) and *"would it have been better to sense things by not actively touching"* (P1). To overcome such challenges, it is crucial for researchers to use simple, relatable examples using existing technology. This is consistent with prior work the value of examples in haptic design [482, 485] and design more generally [226], and reinforces ongoing work into example-based design tools [496, 540].

To support diverse genres of stories - from fantasy and sci-fi to real experiences and children's tales - we found that a combination of real-world and abstract objects and examples was most effective in demonstrating haptic feedback. Abstract examples allowed participants to exercise their imagination, while real-world objects provided a practical demonstration of how haptics could emulate real-world scenarios. For example, one participant suggested using a candle as a real-world object to drive the narrative in a story. Another participant found that the combination of familiar and foreign objects was powerful, as it provided a balance between the known and the unknown. This approach not only helped participants understand the concept of haptics better but also sparked their creativity in incorporating haptic feedback into their stories.

3.7.5 Moderation: Be aware of overuse and unintentional interpretation of haptics

It is crucial for non-haptician storytellers to be aware of the potential for overuse and misinterpretation of haptics in storytelling. Overuse of haptics can lead to a sensory overload, detracting from the main narrative and potentially causing confusion or discomfort for the audience. One participant noted the lingering sensation after using the Tickle Trunk's

vibrational feedback for an extended period, stating *"I still feel the buzz"* (P5), while another emphasized that *"need to find a right balance, what is useful and what is over the top"* (P2).

This is particularly important in the context of VR storytelling, where the immersive nature of the medium can amplify the effects of haptic feedback. Therefore, it is essential for storytellers to be aware of the duration and intensity of haptic cues in their stories.

The subsection 3.5.3 highlights the emotional response elicited by haptic feedback, thereby emphasizing the need for careful consideration of the intended purpose behind the utilization of haptics. Misinterpretation of haptic cues can lead to confusion and disconnect between the story and the audience. For instance, the "Heartbeat" vibration effect used in the Gaming Chair device can evoke different emotions depending on its usage in the story. While it was used to express the vibration of a bird's heartbeat by one participant, another used it to simulate fear. This highlights the subjective nature of haptic feedback and the need for careful consideration of its potential interpretations.

Furthermore, the emotional impact of haptics should not be overlooked. Previous literature [144, 519] has shown a powerful connection of haptics in eliciting strong emotional responses. Therefore, storytellers should be mindful of the potential emotional reactions that their use of haptics may provoke, especially when dealing with sensitive topics such as institutionalized racism or abuse. During an in-person workshop, collaborator C5 noted that "haptics should not enhance realism, that is not what we're looking for, that would be further harm.". Therefore, caution must be exercised in determining when and how to incorporate haptics. Ultimately, the use of haptics in storytelling should enhance the narrative and emotional engagement, not detract from it or cause unnecessary distress. Echoing

this caution, we recommend a calibrate-then-escalate guideline: begin with mild, symbolic cues to gauge audience comfort before layering higher-intensity effects. In short, what is special about haptics—its immediacy, embodiment, and interpretive openness—can be a narrative strength or a liability; recognising that dual potential is the first step toward responsible design.

3.8 Conclusion

This research paper provides new insights into the initial haptic design process between storytellers and hapticians, and the usefulness of the FPI process. The successful use of the FPI process and associated tools (such as the Haptic Mini-Tour, Tickle Trunk, and Worksheet) by participants validates the effectiveness of structured discussions between storytellers and hapticians, as detailed in subsection 3.7.1, subsection 3.7.2, Figure 3.12a and Figure 3.12b. In conclusion, while haptic technology offers immense potential to enhance the storytelling experience, its successful deployment is contingent on the quality of discussion between the stakeholders involved in its development. The FPI process and its associated tools can serve as resources in facilitating this discussion, thereby bridging the divide between hapticians and storytellers. This paves the way for a more inclusive, immersive, and enriching storytelling experience for all.

3.9 Limitations and Future work

Our implementation of the FPI process was constrained by the resources available at the time. The selection of devices for the Mini-Tour and the design of the Tickle Trunk widgets were limited to those already in our lab. However, hapticians should feel free to incorporate any other devices and widgets available to them during the Feel and Imagine steps. In fact, we anticipate that the FPI process should be adjusted to suit the specific needs and capabilities of each haptics team.

Hapticians should strive to present a wide range of haptic feedback options for their projects. As we mentioned in subsection 3.7.4, some of the devices that participants desired were not included. Therefore, developers and designers should leverage the modular design of the Tickle Trunk to add new widgets, and use demos available in commercial devices to showcase appropriate examples and interactions for their project. The flexibility of the Introduction step allows for the addition or removal of devices and components based on availability.

In our evaluation, there may have been a novelty effect as participants were new to haptics. However, the system is designed to support newcomers to haptics, so we believe that our results are applicable to the intended use cases: facilitating initial discussion between hapticians and non-haptician storytellers.

We did not explore alternative sequences for the FPI process in this study. We always conducted the FPI steps in the same order - Feel, Play, and then Imagine. This sequence was intentional: we felt it was important to first provide a broad context of how haptics

can fit into a final application (Feel), then reveal the diversity of haptic design and enable exploration (Play), and finally discuss the goals of the design process after this understanding (Imagine). However, hapticians can adjust the order as needed, for example, if the process is used for longer or more iterative sessions.

Finally, our participants proposed some haptic effects that may be quite complex. One limitation is that the FPI process is designed to generate ideas without focusing too much on technical details. At some point, hapticians will need to set realistic expectations about what is achievable. We hope that the Introduction step which uses Tickle Trunk as a custom device and Haptic Mini-Tour commercial-grade haptic devices, will help set reasonable expectations or serve as a reference that the team can use later.

Chapter 4

Collaboration: CHI Workshop

Foreword. This chapter offers a *breadth-first* view of collaboration in haptics. It looks into two teams working under shared constraints to collaboratively create a haptic system. It complements the companion Chapter 5 on a long-term case study by providing generalizable observations, while the depth chapter grounds and tests these patterns over time.

Collaboration is essential for translating complex haptics into meaningful experiences across disciplines. This chapter presents a participatory design workshop at CHI in which researchers, educators, students, and technologists formed small teams, used the *Tickle Trunk* kit, and rapidly brainstormed and prototyped early haptic interface ideas. Post-session surveys indicated that *Role Clarity* scored considerably lower than *Communication Quality* and *Tool Satisfaction*, and comments highlighted uncertainty about responsibilities and dominance effects. Teams favored informal, hands-on ideation - talking through ideas, sketching, paper prototyping, trying components, which accelerated brainstorming but

hampered consistent documentation. Inclusive participation hinged on shared technical understanding and equitable hardware access; participants asked for more kits, improved ergonomics, and quick refreshers to establish a common baseline.

4.1 Introduction

Designing meaningful haptic experiences inherently demands interdisciplinary teamwork. Engineers, designers, and domain experts must work in together to translate technical capabilities into rich, contextually relevant tactile interactions. This diversity of expertise, however, often brings communication gaps and language barriers between disciplines [482, 493]. In the emerging field of haptics, effective collaboration is both crucial and challenging, and there is a clear need to better understand how diverse teams can co-create in this space [146]. Motivated by this gap, our work examines how collaboration unfolds during the early stages of haptic design, when ideas are fluid and prototyping is rapid. We draw on participatory design traditions in HCI, which emphasize designing *with* rather than *for* users, to investigate how inclusive, cross-disciplinary teamwork can be fostered for haptics [64, 67, 17].

To explore these questions, we conducted a one-day participatory design workshop at CHI 2024, called Haptic Playground, which investigated interdisciplinary collaboration in early stage haptic prototyping. In this workshop, mixed teams of researchers, educators, students, and technologists were assembled and equipped with the "Tickle Trunk" haptics toolkit, a collection of plug-and-play sensors, actuators, and components—to rapidly brainstorm and prototype novel interface ideas. The Tickle Trunk toolkit was originally



(a) Group 1 discussing ideas for a haptic device



(b) Group 2 discussing ideas for a haptic device

Figure 4.1: Participants engaging in the Haptic Playground workshop, where they held group discussions and actively experimented with various inputs and outputs. Teams collaboratively explored interactive ideas, tested various widgets, and shared insights to discover creative possibilities using the toolkit.

conceived to democratize haptic design and lower technical barriers for newcomers, making it well-suited for our goal of hands-on, inclusive experimentation. During the session, each multidisciplinary team freely combined their skills to sketch concepts, discuss use cases, and tinker with hardware in real time. This informal, hands-on approach mirrored a playground ethos, encouraging participants to break out of disciplinary silos and learn by doing [84]. By the end of the day, teams had built simple haptic interface prototypes and shared reflections on their collaborative process. Through surveys and open-ended feedback, we collected both quantitative and qualitative insights into their experience, covering aspects like role clarity, communication, and inclusion practices to analyze what helped or hindered effective collaboration.

This chapter reports on the Haptic Playground workshop to study collaborative proto-

typing in haptics teams. We outline the setup, participants, and procedures, and present the key themes that emerged from the workshop.



(a) Team A demonstrating their prototype.



(b) Team B demonstrating their prototype.

Figure 4.2: Workshop participants demonstrating their collaboratively designed haptic prototypes. They explained their ideas and the functionalities of the prototypes they created together during the session.

4.1.1 Method

On May 11, 2024, at CHI 2024, the Workshop on "Haptic Playground: Empowering Inclusive Haptic Design for Everyone" was held; details about the workshop are available at [260]. The workshop was organized to explore haptic interaction through practical collaborative prototyping activities using the Tickle Trunk method. Participants, representing diverse academic and industry backgrounds in Computer Science, HCI, Haptics, UX, and Engineering (shown in Figure 4.1), were assembled into multidisciplinary groups. Teams were encouraged to collaboratively generate, refine, and prototype ideas through informal

idea sharing methods such as verbal discussion, sketching, and hands-on exploration of hardware components (shown in Figure 4.2). After the collaborative activities, participants completed surveys evaluating their experiences on dimensions including role clarity, collaboration effectiveness, communication quality, and skill utilization (see Figure 4.4). Additionally, open-ended questionnaire responses were collected to identify insights related to collaborative methods and inclusion practices. The primary objective was to understand how participants' diverse expertise and collaborative approaches influenced their ideation, communication, role dynamics, and overall experiences during haptic prototyping activities.

4.1.2 Participants

We recruited 14 participants spanning diverse academic and professional backgrounds, clustered into four main categories: graduate researchers, post-doctoral researchers, industry professionals, and a faculty advisor (see Table 4.1). Participants differed widely in their experiences, ranging from early-career graduate students to highly experienced faculty, providing multidisciplinary perspectives for the collaborative activities.

4.1.3 Procedure

Participants were divided into two teams, each provided with a Tickle Trunk (see subsubsection 3.3.1 and subsection A.1.1) toolkit containing various widgets and components for prototyping haptic feedback device. Sessions commenced with an initial questionnaire gathering participants' professional backgrounds, skillsets, and prior experience with rele-

Cluster	Count	Roles and Backgrounds	Years of Experience
Graduate Researchers	6	MSc/MPhil/PhD students in CS, HCI, and user studies; includes a CS PhD working on thermal actuators and a first-year PhD designing deformable interfaces	0-5 yrs (Mean = 2.8)
Post-doctoral Researchers	3	HCI and haptics post-docs working on perceptual illusions, VR, and hardware prototyping	1-9 yrs (Mean = 5.0)
Industry Researchers, Engineers, and Designers	4	UX researcher at a major tech company; industrial and mechanical designers; device engineers focused on pneumatics and vibrotactile design	0-6 yrs (Mean = 3.5)
Faculty Advisors	1	Faculty member in an engineering discipline supervising haptics	14 yrs

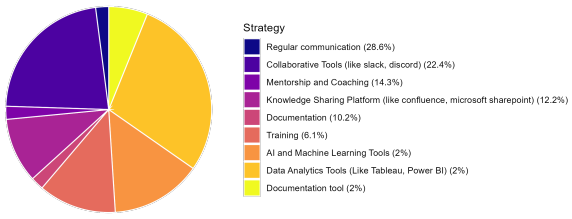
Table 4.1: Participant clusters by career stage, representative roles, and years of experience in haptics.

vant collaboration strategies and prototyping tools. Additionally, the initial questionnaire gathered details on participants' typical collaboration strategies and tools previously used in their haptics projects (see Figure 4.3). This workshop received University of Waterloo REB ethics clearance (REB #44481), and the consent form, participant feedback letter, and full pre/post questionnaires used in the study are provided in Appendix C; the exact documents are included so readers can audit the protocol and reuse the measures.

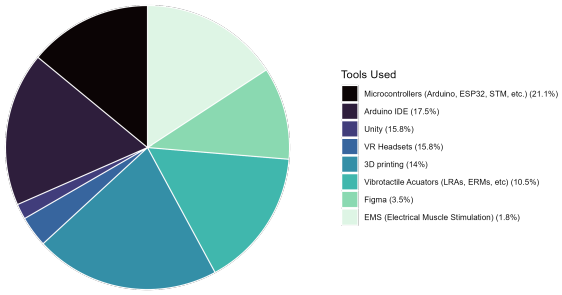
Teams were first given an exploratory period, during which they familiarized themselves with the toolkit items by freely interacting, discussing ideas, and examining possibilities based on their collective skills and experiences. Following this exploration phase, teams self-organized and collaborated independently to prototype their haptic interface concepts. Participants adopted techniques such as role-playing, paper prototyping, and "Wizard-of-

Oz" simulations to support their idea construction, idea sharing, and prototyping progress.

At the session's conclusion, teams presented demos and concepts developed during their sessions. Participants subsequently completed surveys assessing their collaborative experiences, covering dimensions such as role clarity, communication quality, collaboration effectiveness, tool satisfaction, skill utilization, and learning from team interactions. Additionally, open-ended questions prompted participants to share qualitative reflections on the idea-sharing methods used, collaboration challenges encountered, and suggestions for enhancing inclusion during collaborative prototyping sessions.



(a) Distribution of collaboration strategies



(b) Breakdown of tools used

Figure 4.3: Figure set illustrating strategies and tools used in participants' past projects. a) The pie chart displays the distribution of collaboration strategies, such as regular communication and collaborative tools used for their haptics projects. b) The pie chart shows the variety of tools participants have used before for their haptics projects

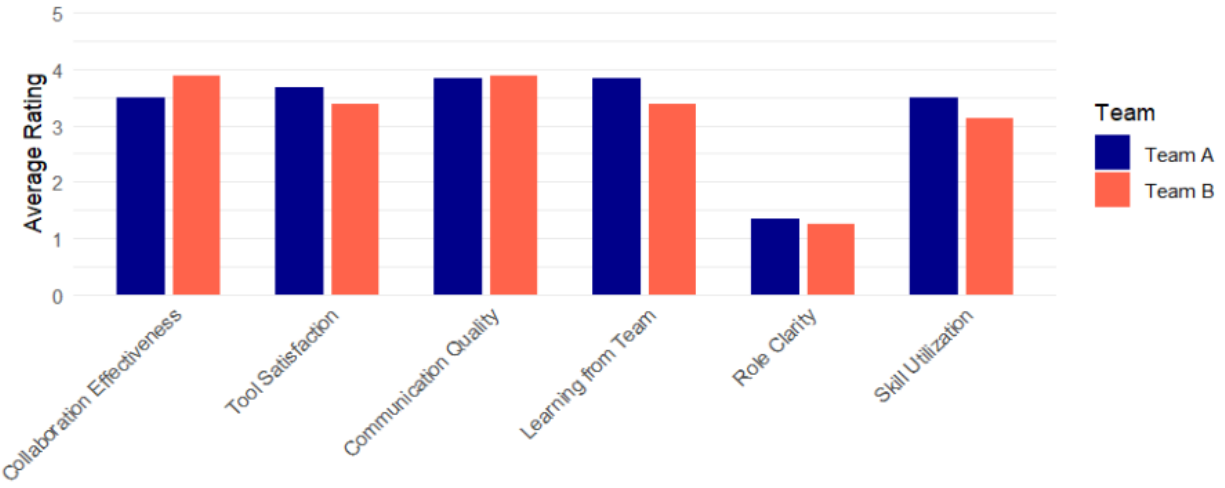


Figure 4.4: Comparison of average ratings between Team A and Team B across various collaboration metrics, showing differences in areas such as tool satisfaction and skill utilization.

4.1.4 Results

I informally reviewed the survey responses and workshop notes side-by-side, captured recurring ideas on sticky notes, and clustered those notes by similarity. This grouping surfaced three recurring themes:

I) Role Ambiguity as a Barrier to Effective Collaboration

Participants frequently highlighted challenges related to unclear roles within their teams. Post-activity survey results reflected these concerns, with *Role Clarity* receiving notably lower scores compared to other collaboration dimensions such as *Tool Satisfaction* and *Communication Quality*, which participants consistently rated above 3.5 for both teams (see Figure 4.4). Qualitative feedback emphasized uncertainty and ambiguity around in-

dividual responsibilities. For instance, one participant stated, "*It was hard to know how to start and who was supposed to do what*," while another pointed out that "*one person was talking loud, which sometimes creates a situation where others cannot effectively contribute.*" This ambiguity appeared to hinder teams' abilities to effectively organize and focus their collaborative efforts, suggesting clearly defined roles and explicit interaction guidelines as critical factors for improving overall collaboration.

II) Informal and Hands-on Idea Generation

Participants predominantly used informal and hands-on approaches for idea generation and communication during group activities. Idea sharing methods included predominantly "verbal" interactions, with additional methods such as "sketching", "paper prototyping" and physically "trying out" ideas. A participant described their method explicitly as "*verbal, just throwing out ideas into the discussion*" and highlighted the advantage of "*playing around with the components and bouncing ideas off each other.*"

However, although informal approaches supported flexible and rapid idea generation, they presented barriers in terms of structured documentation, with teams noting challenges later when translating verbally communicated ideas into tangible outcomes.

III) Facilitating Shared Technical Understanding and Accessibility

A third noticeable pattern related specifically to technical resources and access. Multiple comments suggested improving practical constraints, including increasing hardware availability ("multiple toolkits"), improving hardware interaction affordances ("longer wires for

toolkit elements"), and providing clearer initial technical grounding ("explaining basic concepts if needed, not assuming background knowledge"). Collectively, these inputs indicate a common perception that inclusive participation depends significantly upon equitable and thoughtful technical setup and resource allocation.

4.2 Conclusion

The CHI workshop provided a focused opportunity to examine how interdisciplinary teams collaborate during early stages of haptic prototyping. By bringing together researchers, educators, students, and technologists to work with the *Tickle Trunk* toolkit, we observed both the barriers and enablers of effective collaboration in a short term colloborative design setting. The workshop underscored three recurring challenges: role ambiguity, which limited coordination and equitable participation; the predominance of informal, hands-on ideation, which accelerated creativity but hindered systematic documentation; and the need for shared technical understanding, which depended heavily on equitable access to hardware and resources.

Taken together, these themes highlight that collaboration in haptics requires more than assembling diverse expertise—it also requires deliberate structuring of roles, facilitation of idea capture, and careful design of technical setups that lower barriers for all participants. These findings complement broader discussions in HCI and Computer-Supported Cooperative Work (CSCW) on bridging disciplinary language gaps and building shared literacy in emerging technical domains [17, 65]. While our workshop was limited in scope and duration, it offers concrete insights for designing inclusive collaborative environments, both

in research and in practice, where haptics is central.

Chapter 5

Collaboration: Haptic Sankofa

Foreword. This chapter offers a depth-first view of collaboration in haptics. It presents a four year, community engaged co-design that traces collaboration in situ—from relationships and ethics to tangible boundary objects and integrated interaction design. It grounds and refines the broad themes of the Chapter 4 workshop in sustained practice, showing how coordination, trust, shared vocabulary, negotiation, and ownership play out over time.

Collaboration is critical to translating complex technologies into meaningful human experiences, particularly when work spans multiple disciplines and stakeholder communities. This chapter analyzes a four-year, interdisciplinary co-design that produced *Haptic Sankofa*, a tangible haptic interface intended to foster relational presence in VR narratives of social justice. Our analysis surfaces six themes - coordination, trust, communication, technical competence, negotiation, and shared ownership and operationalizes them as practices: clarify roles and rhythms; use boundary objects and tangible prototypes to bridge disciplines; maintain a shared vocabulary and visual documentation; build haptic literacy

through hands-on training; structure negotiations and consent checkpoints; and cultivate collective accountability through shared artifacts. Together, these practices provide concise guidelines for multidisciplinary teams developing haptic systems.

5.1 Introduction

Rooted in the Scandinavian Cooperative Design movement, this participatory design in HCI shifted the paradigm from designing for users to designing with them, championing the inclusion of workers and other diverse stakeholders in a shared process of inquiry and creation [64, 67]. The central idea remains a commitment to empowering those with lived experience, ensuring that technological outcomes are not only usable but also deeply relevant. Within HCI, the subfield of Computer-Supported Cooperative Work (CSCW) has long grappled with a core challenge in this domain: the 'social-technical gap", which describes the persistent challenge between the fluid, richly contextual nature of human social activity and the formal logic of computational systems [17]. This gap is not a only technical problem to be solved but a fundamental tension to be managed in any technology that augments social and personal life.

Haptic technologies amplify these stakes, extending the socio-technical gap into an embodied domain. Immersive systems that engage the sense of touch do not merely mediate information, they aim to engage user's full body movements and emotions by translating digital information into physical experiences [264, 144]. This creates a design challenge. The gap is no longer just between social norms and system rules, but between the complexity of lived, felt experience and the technical affordances of sensors and actuators. Creating

meaningful haptic interactions is therefore an intrinsically collaborative act, demanding a tightly woven partnership between engineers who understand actuators, designers who shape experience, and domain experts, therapists, or community storytellers - who hold the contextual knowledge that gives the experience meaning [347, 146].

However, the diversity of expertise required to create rich haptic experiences often creates significant collaborative hurdles. The different languages, priorities, and work rhythms of engineers, designers, and community partners can lead to misunderstandings and hinder progress. The need for effective collaboration is clear, yet there is less established guidance on how these interdisciplinary teams work together, especially when navigating the unique challenges of designing for the sense of touch. How can a team build a shared haptic literacy? How can technical possibilities be reconciled with cultural or emotional sensitivities? Answering these questions is critical to advancing the field.

This chapter presents a four year, participatory co-design case study of *Haptic Sankofa*, a tangible haptic interface intended to foster relational presence in VR narratives of social justice. We detail the collaboration's context, stakeholder roles, decision points, and design iterations, and analyze the practices that enabled sustained engagement and trust-building. Our analysis surfaces six cross-cutting themes - coordination, trust, communication, technical competence, negotiation, and shared ownership, which we operationalize into actionable practices for multidisciplinary haptics teams. We conclude with concise guidelines for designing haptic systems oriented toward relational presence.

5.2 Related Work

The chapter 2 provided a broad overview of the history, applications, and core challenges in haptics development, this section presents a focused literature review directly relevant to the studies contained within this chapter. The following review examines literature on presence and immersion within VR, alongside the advantages of restorative justice in addressing complex social justice narratives.

5.2.1 Presence and Immersion in VR

VR technology has transformed the way we interact with digital content, offering a sense of immersion that is unparalleled by other mediums [153, 516]. Immersion is a state of deep mental involvement in which the individual may experience disassociation from the awareness of the physical world due to a shift in their attentional state [25]. It is a subjective sensation of being present in a virtual environment (VE) despite being physically located elsewhere, and is a critical aspect of VR experiences [153, 449]. This is further characterized by the plausibility illusion, where events in the VE are perceived as real-life occurrences [514]. The impact of immersion is particularly profound in VR storytelling, where it enhances user engagement [247], increases intrinsic motivation for learning [374], increases presence while decreasing sickness [570, 569], and improves performance in training [600]. However, the implementation of immersion is not without its challenges and potential risks. It is crucial to consider the context and its psychological effects, as immersion in harmful environments can have negative effects on users.

VR immersion can potentially induce risks, including long-term psychological impacts that can cause negative emotional and behavioral changes. Bailenson [47] defines VR immersion as psychological presence, asserting that it can induce significant and enduring transformations in individuals, akin to real-world experiences. Research has identified four areas of risk associated with immersion in VR: the unknown psychological impact of long-term immersion, the danger of neglecting embodied interaction and the physical environment, privacy-related hazards, and exposure to risky content [351]. Given the human mind's plasticity, immersive VR can not only change sensorimotor contingencies [50], it also carries potential risks of lasting psychological effects [457]. When a virtual body is attacked or threatened, or harm is caused to a virtual character, the viewer responds subjectively and physiologically as if the attacks were real [461, 427, 517]. Violent VR video games have been shown to have negative effects on emotion, cognition, and behavior [578]. While there is limited evidence showing negative cognitive or behavioral effects of violent, scary, or sexual media [152], body ownership/embodiment in VR allows users to experience events first-hand. This perspective could potentially alter the effects of violent or frightening media [351]. Essentially, VR can change how individuals perceive themselves and others, both positively and negatively [515]. In therapeutic settings, for instance, VR has been found to induce a strong urge to gamble, comparable to physical Electronic Gaming Machine (EGM) terminals found in casinos [135]. For instance, a study found a significant impact of immersion on real-life decision-making simulated by the Iowa Gambling Task, with participants in the VR group drawing significantly more disadvantageous cards than the control group [404].

The increasing integration of VR across various domains has paved the way for ex-

ploring sensitive topics like sexual abuse, empathy and mental health through immersive experiences [301, 212]. However, a critical gap exists in understanding the short- and long-term physiological impacts of VR, and insufficient knowledge about who and what types of individuals are using VR [279]. Sensorimotor interactions in immersive VR have been shown to change the perception of time and user expectations of their physical movements [50] and it has also been shown to harm learning outcomes due to a lack of immediate or long-term memorization using high feedback conditions [444]. Ethical considerations for immersive VR in school environment are also highlighted [524]. As we continue to explore the potential of VR, it is crucial to balance the benefits of immersion with the potential risks, ensuring a safe and beneficial experience for all users, especially in the learning environment.

5.2.2 Haptic Feedback and Immersion

There is a large and growing body of work showing that haptic feedback can enhance presence, immersion, and task performance in VR environments. Studies such as the one conducted by Kreimeier et al. [302] highlight that haptic feedback, particularly vibrotactile feedback, significantly outperforms visual feedback in enhancing the feeling of presence within VR environments. In educational settings, the impact of haptic feedback becomes even more pronounced. Lontschar et al. [338] explored how haptic feedback in VR learning environments aids task comprehension and execution, underscoring its importance in interactive educational applications. By engaging the sense of touch, learners can better understand complex concepts and procedures, which can be particularly beneficial in fields

where hands-on experience is vital, such as medicine, engineering, and skilled trades.

The evolution of haptic devices has been instrumental in advancing VR technology. Innovations in this area, such as the development of haptic gloves and wearables, enable users to interact with virtual objects in a more natural and realistic manner. Qi et al. [436] discussed the creation of an untethered, lightweight pneumatic glove that provides kinesthetic and cutaneous sensations, allowing for a more enriched and realistic VR interaction. The influence of haptic feedback on immersion and presence is further underscored by research focusing on the congruency of visuo-haptic feedback. **?**] examined how matching visual and tactile feedback in VR can affect user experience, especially in immersive video games and simulations. Their findings suggest consistent visuo-haptic feedback can significantly enhance the user's immersion, making the virtual environment more convincing and engaging. When it comes to performance in VR, haptic feedback has been shown to have a considerable impact. For example, Fröhner et al. [172] demonstrated that different types of haptic feedback, such as force and vibrotactile feedback, could significantly affect how users perform specific tasks within VR . Particularly, force feedback has been associated with improved performance in tasks that require precise control or strength, further emphasizing the value of integrating comprehensive haptic feedback in VR systems.

5.2.3 Restorative Justice as Relational Conception of Justice

Restorative Justice has been extensively explored in the context of transitional justice, focusing on its relational principles and its potential for transforming relationships [330, 329, 329, 332]. This approach to justice is seen as a significant shift from the traditional

punitive/retributive justice system, which focuses on individual accountability, to a more inclusive, participatory, and community-centered justice process [72, 328]. The limitations of the traditional approach to transitional justice often focus on dealing with past injustices through punitive measures [535]. Restorative justice, on the other hand, requires a transformation of relations and a focus on understanding the past to inform a more just future [288]. As Llewellyn [328] argues, "Transitional justice requires the transformation of relations. It requires dealing with the past but not to even the score or wipe the slate clean by assigning blame and meting out punishment. Rather, the past must be examined and understood for what it reveals about the nature and structure of relations and the transformation required to realize a just future." This approach is particularly relevant in contexts transitioning from conflict to peace and/or authoritarianism to democracy [455]. Restorative justice rejects the idea that individuals and their conduct can be dealt with apart from the related context, causes, and circumstances. It expands the focus beyond individual relationships to consider the systems and structures that contributed to harm. Doing justice this way engages those directly affected and involved in the work of transformation of relations toward a just and sustainable future [289]. Restorative justice cannot be achieved through one size fits all, fixed sets of practices. Instead, it must be guided by the relational principles that inform the development or adaptation of different practices and process models [139, 215].

Restorative justice has been effectively utilized in schools, workplaces, and everyday life to address conflicts and wrongdoing [245, 283, 557]. For instance, The Young New Yorkers restorative justice media-arts program used digital storytelling to allow participants to reflect on their crimes and their impact, fostering a process of self-improvement and

community betterment, highlighting the need for more research on participant perspectives in restorative justice initiatives [381]. Similarly, the restorative justice process has shown positive effects in dealing with post-traumatic distress in young offenders [583]. Restorative Justice in mental health settings, though resource-intensive, can effectively address trauma by rebuilding confidence, reducing distress, and promoting resilience and recovery [379].

The potential side effects of inadequately managing VR narratives that deal with challenging themes such as trauma, horror games, and anxiety are significant and multifaceted [351, 66, 522]. Poor management of these narratives can lead to increased emotional distress, exacerbation of pre-existing mental health conditions, and the potential for re-traumatization [460, 169]. Restorative justice based on relational principles helps to deal with challenging narratives and storytelling by providing a platform for reflection, empowerment, and connection [469]. The interplay of restorative justice concepts can drive a synergistic evolution towards more inclusive, empathetic, and technologically enriched approaches to justice and human connection [331]. Relational presence is derived from these relational principles of Restorative Justice. Roberts-Smith et al. [451] describes it as a form of presence in a virtual learning environment where the focus is not on replicating a real-world experience, but rather on fostering an understanding and relationship with the stories and experiences of others. This concept is not about generating a traditional sense of presence where a virtual experience feels akin to a real-world experience. Instead, it is about acknowledging that one is witnessing a story being told through the perspective of another person, an experience that could never be replicated in the real world.

Relational presence was already a guiding concept in the previously developed VR experience (subsection 5.3.1) to incorporate the storyteller's voice and enable participants



Figure 5.1: Screenshot from the DOHR project captures the user's viewpoint while experiencing one of the stories. In the project, users can look around the rooms or areas of the house where the story unfolded, while the events are narrated.

to witness challenging narratives. In this paper, we have employed relational presence to construct a tangible interface to complement this experience and understand how haptics can be integrated while maintaining relational presence.

5.3 Haptic Sankofa Project

5.3.1 Design Context and Process

The Digital Oral Histories for Reconciliation is a community-driven research project involving community storytellers, representatives from the Nova Scotia education system, artists, and researchers to develop a VR experience [188, 334]. The project focused on a former care institution for African Nova Scotian children in Dartmouth, Nova Scotia from 1921 until the early 2000s.

The VR experience, which lasts between thirteen to fifteen minutes, is designed to

support learning activities that are based on the principles of historical thinking and oral history education, and on a restorative approach to learning. After the user puts on the Oculus Rift VR headset, the VR experience begins with a short documentary-style 360º video segment, introducing the three storytellers at the current site of the care institution. Then, the storytellers each tell a story about the care institution which involve topics of neglect, abuse, and resilience. During these stories, a multi-modal blend of 3D graphics, 360º and 2D video, 2D images, environmental and spatially-located sound, voiceover narrative, and text complements the storyteller's voice. The experience creates awareness using restorative justice and encourages them to share what they have learned in a way that does justice to the historical experiences of the individuals involved. The intent is for students to consider their relationship to, and responsibility for, addressing the history of harm, based on systemic racism.

The DOHR was part of the former residents' broader "journey to light", their comprehensive journey which includes sharing their stories and their work towards restoration and reconciliation; the DOHR is one component of this broader work committed to restorative principles [7]. These principles directly informed design decisions of the DOHR experience. For example, the visual style shifts from 360º video during the bookended intro and outro scences to mixed-mode, impressionistic representation of the lived experience in a real-world environment. This approach avoided the use of avatars and limited interactivity to opportunities for observation; story events are not explicitly portrayed, and the storytellers' voice is designed to be immediately beside the listener.

The design of this experience led to a different understanding of what it means to be present in a virtual environment. Because the DOHR experience was oriented around



Figure 5.2: A Wooden Sankofa statue used by the DOHR team, and later haptic design team, as a talking piece during the in-person discussion about the stories in a sharing circle. This statue formed the basis for our later 3D-printed prototype.

relational presence [451], which focuses on different attributes like witnessing over interactivity and affective dissonance over satisfaction, any haptic or tangible interface needed to be designed in a thoughtful, nuanced way to adhere to project constraints and goals. Nevertheless, our storytellers and team members were curious and excited to explore the use of new technology.

Sankofa

The Sankofa is a word from the Twi language of Ghana, often translated as "Go back and get it" or "It is not taboo to go back and fetch it" [7]. The concept is visually represented by a bird with its head and neck reaching backward to gather an egg in its beak, while its feet face forward. This imagery symbolizes the importance of retrieving and learning from the past to move forward wisely. Sankofa is also tied to the proverb "se wo were fi na wosankofa a yenkyi," which means "It is not wrong to go back for that which you have forgotten" [7].

The Sankofa has specific importance for the storytellers and the team. It was chosen as a symbol of their journey to light, and integrated throughout the relevant work that the storytellers and their collaborators did. This symbolism is apparent through the use of the Sankofa as a symbol for the DOHR, and the use of a Sankofa as a talking piece during a sharing circle and its inclusion in the 360º video of the DOHR Figure 5.2.

Process

We designed Sankofa Interface to improve accessibility and engagement with VR narrative stories. The interface uses haptic interaction to allow users to experience VR stories in a meaningful way, promoting self-awareness, learning, and reflection.

The development of the Sankofa Interface was a multi-disciplinary and collaborative process, drawing on theoretical literature and studies in restorative justice, VR, and haptics. This co-design process involved participants from diverse fields such as restorative justice, VR, dramatic arts, oral history, social justice and education. This approach is in

line with Schön [488]'s concept of design as a reflective conversation with materials, where we engaged in a dialogue with the theoretical, empirical, design materials, stories, and the audience who will be using the interface. The design of the Sankofa Interface was finalized through iterative development and ongoing critique of design concepts working with our storytellers and collaborators.

This work was conducted entirely within our research team, with community co-designers participating as active team members throughout. No external participants were recruited or studied; the process was exclusively collaborative and relational, consistent with restorative-justice principles. Accordingly, a separate institutional ethics review was not sought for this design phase because it did not constitute human-participants research beyond the research team.

Our initial steps were to establish relationships with the different members of the team, and to learn about each other's expertise. The haptics team experienced the DOHR experience crafted by our other team members. The objective was to comprehend the narrative structure of each story and the required user navigation through different story sections.

The entire team met several times online at the outset of the project to establish connections, understand the project's mission, and introduce the concept of haptics to the rest of the team. In addition, various questions regarding the VR project were discussed during multiple online and in-person sessions. The diversity among the individuals present in the discussion contributed to a comprehensive understanding of the project requirements and reflection on which design worked best for Sankofa. Our collaborators provided guidelines and answered queries regarding restorative justice principles, relational presence, and the design of Sankofa. Both in-person and remote methods were used to accurately determine



Figure 5.3: A variety of 3D-printed Sankofa prototypes, varying in shape, size, and weight. These tangible models were created to enable our collaborators and storytellers to physically interact with the interface to assess their relevance and comfort.

what the collaborators were seeking. We discussed how they wanted to represent haptics within the stories and how they envisioned participants interacting with these narratives.

We organized a 1-day workshop to further develop relationships, provide the haptics team an introduction to relevant places involved with the project, and to introduce other team members to haptics. As some members had only interacted online before, an in-person meeting let them meet face-to-face, and afforded informal time to get to know each other. The haptics team had not visited the space in which a museum exhibit might be deployed, and so were given a tour of the museum.

As the DOHR team and storytellers had limited lived experiences with haptic and tangible interactions, the haptics team gave an introduction to the subject. A set of polished haptic devices alongside a toolkit with several modalities [43] was brought to the workshop

so that all collaborators and storytellers could experience a broad set of types of feedback first-hand. Abstract objects served as a starting point for holding a tangible object, input modalities like gestures or object manipulations, and output modalities of different haptic effects such as vibration, heat, shape change, and texture. A wide range of effects was presented to assist the storytellers and the DOHR team in envisioning which type of haptic feedback and tangible object aligned with their stories and which did not.

As part of this session, the haptics team also brought several Sankofa objects (Figure 5.3) to offer collaborators and storytellers additional opportunities for involvement in the design process. We constructed Sankofa with different materials, shapes, and sizes. Initially, we created both a 2-D and 3-D model of the 3D-printed Sankofa.

5.3.2 Interface Design

Through follow-up iteration and discussions with our collaborators and storytellers, we converged on a single design: a tangible interface based on the Sankofa statue.

The outcome of our in-person workshop resulted in several directions. We agreed that we could not represent anything in the virtual world, i.e., no creaking floorboards or touchable virtual objects as physical props. Instead, we focused on metaphorical and non-diegetic options before, during, or after the experience.

Prominent design ideas included:

- physical actions involving light, such as lighting a candle or walking through a spatial array of lights;
- warmth, especially as a way to indicate positive affect, safety, or resilience;

- a rock that had significant meaning for the storytellers;
- the sense of "feeling grounded" or stable; deliberate action, inviting the viewer to participate, commit, or actively listen to the experience; and
- the Sankofa as a meaningful object.

Many of these ideas could be combined, such as the rock being warm or feeling grounded, or the candle being lit as a commitment following the experience. The team was also interested in increasing accessibility, both for individuals with sensory or motor impairments, or to reduce or remove the VR controllers which many users may not be familiar with. These ideas were iterated with using visual sketches alongside exploration of possible physical designs.

Although we maintained some ideas (namely, the rock under the feet and the lighting of a candle) for several months up to a second in-person visit, the Sankofa as a meaningful object emerged as the recurring front-runner. This was due to a combination of factors, including metaphorical resonance, the ability to be directly integrated into the VR experience, and possibility of several clear directions for interaction design.

I) Physical Construction

Our iterative co-design process placed substantial emphasis on aligning the physical form factor of the Sankofa interface with the cultural and narrative significance highlighted by our community collaborators and storytellers. Through multiple workshops and reflective design sessions, key physical attributes - including shape, material, and weight were refined to enhance relational presence and cultural authenticity.

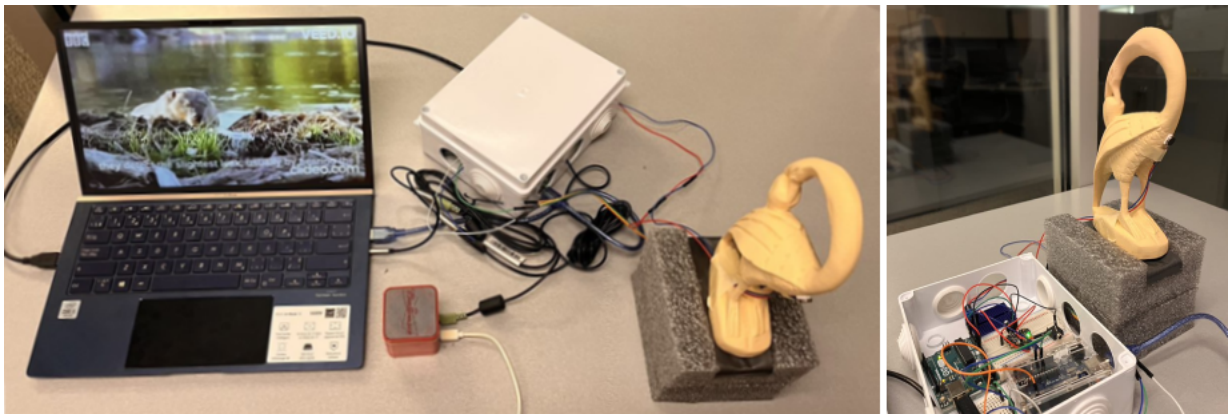


Figure 5.4: The figure shows the early version of the Sankofa prototype, which consisted of a control box, a base, and a 3D printed Sankofa. Initially, the detection of whether the Sankofa was being lifted or not was conducted using a control box that housed the microcontroller unit (MCU), and a base that contained an infrared sensor. The Sankofa was simply a solid 3D-printed item with a Linear Resonant Actuator (LRA) motor attached to its surface. The action of picking up and putting down the Sankofa initiated and terminated the video, respectively. While the Sankofa was being held, it produced vibrations that corresponded to the narrator's voice.

Shape - Initially, our design explorations included both flat (2D) and sculptural (3D) Sankofa prototypes. Feedback from our storyteller collaborators emphasized familiarity and cultural continuity, strongly preferring the 3D form directly scanned from the original wooden Sankofa sculpture (Figure 5.2). The 3D sculptural form, by visually and tactilely referencing the original artefact, reinforced the Sankofa's symbolic role as a storytelling vessel rather than merely a technological object.

Material - Early prototypes, printed with materials such as Polylactic Acid (PLA), Thermoplastic Polyurethane (TPU), and Acrylonitrile Butadiene Styrene (ABS), were perceived by our collaborators as lacking warmth and authenticity due to their "plastic-like" textures. Responding to these critiques, we shifted toward high-resolution resin printing, which better captured the nuanced surface texture of the original wooden sculpture and evoked a tactile authenticity valued by the storytellers.

Size and Weight - Determining the physical dimensions involved testing multiple prototypes with varying heights (6.5–42 cm) and weights (20–550 g). These tests aimed at balancing ease of handling during VR interaction with a meaningful sense of physical presence. Our final design—22 cm in height, 6.5 cm wide, and weighing approximately 350 grams—offered optimal balance, comfort, and symbolic resonance. Adjustments to infill density provided a weight that allowed users to physically sense the Sankofa's presence without causing fatigue. Additionally, the widened base enhanced stability, allowing users to safely place the object during reflective pauses, which was essential for supporting deliberate relational engagement within the VR experience.

Through these collective decisions, the physical design of the Sankofa interface directly embodied principles of relational justice; valuing familiarity, cultural authenticity, and a

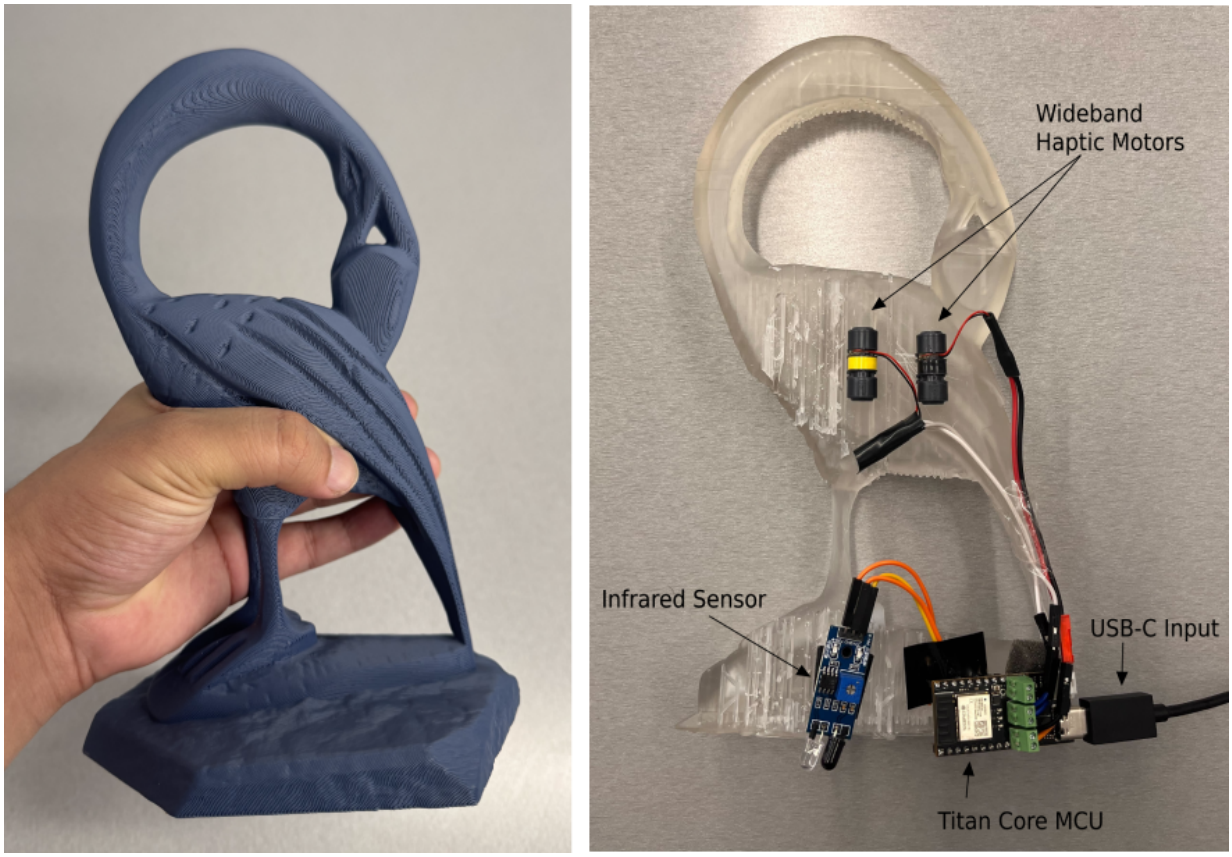


Figure 5.5: The figure shows the latest version of Sankofa, which is used for interaction with VR stories. Sankofa is integrated with a Microcontroller Unit (MCU), a wide-band motor for wide-band vibration, and an infrared sensor for detecting the lifting of Sankofa.

tactile sense of meaningful presence over purely technical considerations.

II) Integrated Electronics

The early Sankofa prototype utilized external sensors and electronics contained in a separate control box (Figure 5.4). However, participant feedback underscored the importance of integrating these components to avoid disrupting the intimate storytelling interactions. Ac-

cordingly, subsequent prototypes encapsulated a Titan Core Microcontroller Unit (MCU), a wideband vibration motor (Titan TacHammer), and an infrared proximity sensor within the Sankofa object itself (Figure 5.5). The choice of infrared over ultrasonic sensors responded to participants' preference for silent, unobtrusive sensing that rapidly detected the Sankofa's lifting action without delay or audible distraction. Similarly, wideband actuators replaced initial LRA and ERM actuators, as they provided vibrational feedback more closely aligned with the subtle, nuanced emotional textures identified by our collaborators as central to relational witnessing in VR storytelling.

III) Vibration Design

Vibration design emerged as a particularly complex site of ethical and aesthetic negotiation within the co-design process. The initial approach directly mapped the storyteller's voice to vibration, aiming to reinforce narrative presence. However, feedback from VR performance expert indicated this approach unintentionally created a tactile "avatar" of the storyteller, thereby undermining the project's commitment to narrative neutrality and non-representation.

In response, we decoupled vibration patterns from direct voice signals. Through iterative co-design sessions, vibrations became explicitly reimagined as subtle relational tethers to the user's own physical presence and the broader cultural symbolism associated with the Sankofa artefact. To accomplish this, vibrations were instead inspired by the natural sounds and movements of the White-necked Rockfowl - a culturally significant bird linked to the original wooden sculpture of Sankofa (Figure 5.6). Unlike direct voice mappings, these bird-inspired vibrations served as gentle tactile reminders of users' embodied pres-

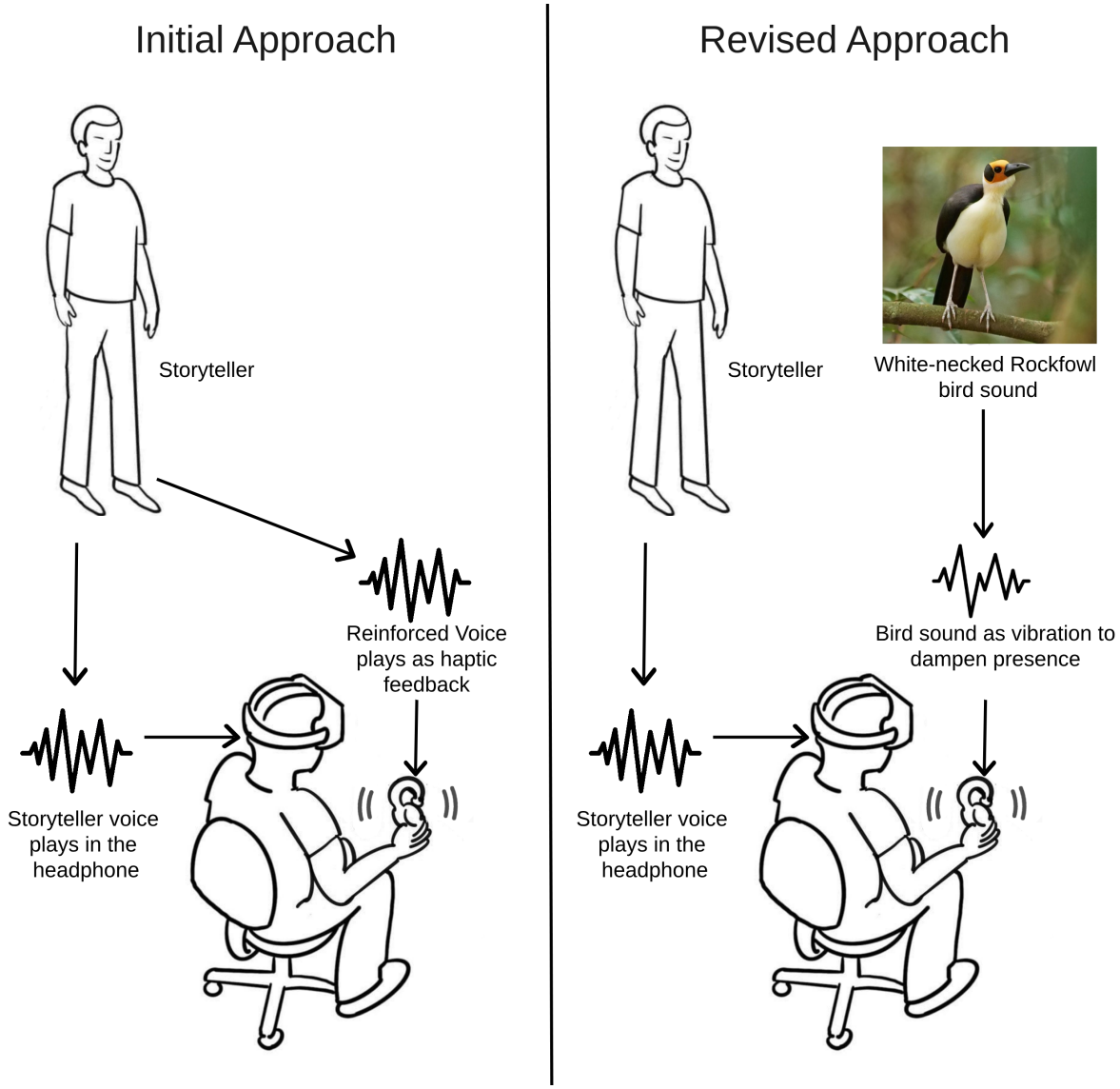


Figure 5.6: The figure contrasts the original and revised haptic designs. Originally, the storyteller's voice played through headphones while a low-frequency, amplified version of the same audio drove vibrations on the Sankofa Interface, reinforcing presence. In the revision, the voice remains audio-only, and Sankofa's vibration is patterned on White-necked Rockfowl calls [70] (see Figure 5.2), intentionally dampening presence.

ence outside the virtual environment. This shift ensured vibrations complemented rather than overshadowed or duplicated the storyteller's voice, supporting intentional emotional distance and reflection.

The refined vibration design incorporated distinct haptic cues - including gestures such as "Hello," "Let's listen," and "I'm here" - each carefully aligned with bird gestures and calls. These vibrations provided meaningful narrative transitions, supported subtle user consent between narrative segments, and regulated immersive intensity during emotionally charged moments (Figure 5.6). By facilitating reflective witnessing rather than immersive identification, this final vibration approach strongly aligned with restorative justice principles of active listening, ethical witnessing, and relational presence. More explanation of vibrational design is availabe in Punit Kunjam's Masters thesis[306].

Taken together, these co-designed elements of physical form, integrated electronics, and vibration design underscore a broader methodological implication for designing technology-mediated restorative justice experiences: successful relational presence depends critically on sustained dialogue, ethical negotiation, and careful balance between technical affordances and cultural authenticity.

5.3.3 Interaction Design

The interaction design of the Sankofa interface was closely intertwined with its vibration design, and both were developed collaboratively to achieve a cohesive final outcome. Similar to the vibrational design, multiple online and in-person sessions were held with collaborators and storytellers to refine and finalize the interaction design. Initially, the original

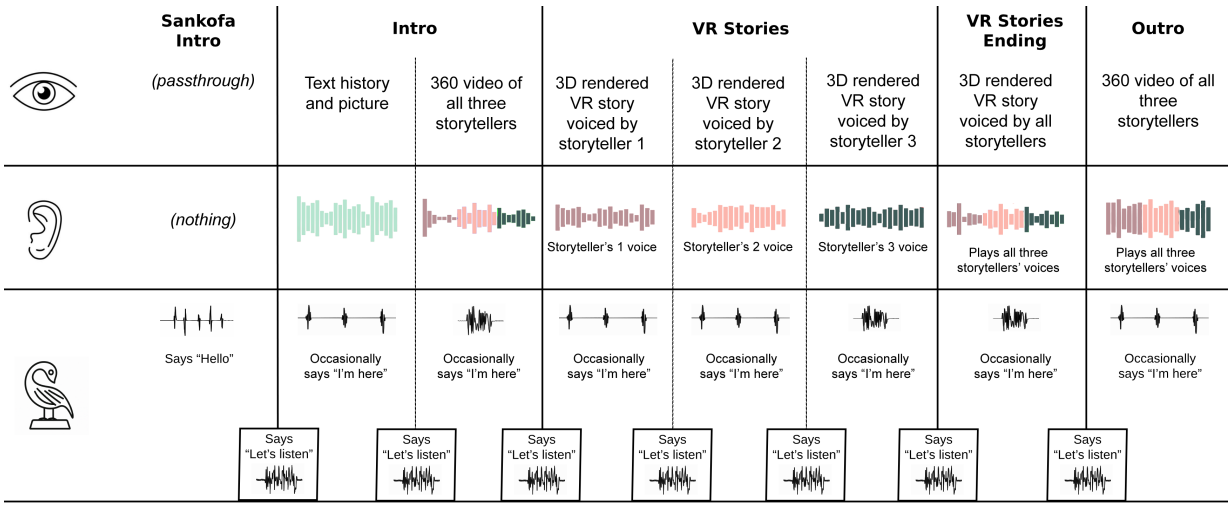


Figure 5.7: VR Project Experience Flow: The experience was originally designed for a VR headset with audio and video modalities, to which we have added a haptic/touch modality. The VR experience begins with an introduction featuring static text and images accompanied by a song. It then transitions to introducing the storytellers in a 360º video at the current site of the former care institution. The user then experiences three stories, one from each storyteller, accompanied by rendered visuals. The stories conclude with a rendered visual featuring all three storytellers, followed by a return to the 360º video of the storytellers at the former site. The experience is initiated when the user picks up the Sankofa. At the very beginning, haptic feedback generates a vibrational pattern for "Hello," followed by the "Let's Listen" vibration pattern. During the VR experience, the "I'm Here" vibrational pattern is occasionally triggered to subtly dampen the user's immersion, reminding them that they are outside the virtual world and experiencing the stories in a safe and reflective environment.

DOHR relied on VR controllers for actions such as play, pause, stop, and menu navigation. However, traditional input methods, such as joysticks or buttons, proved incompatible with the Sankofa's design and required additional user training, similar to other VR controllers. To honor the cultural significance of Sankofa and preserve its form, the design transitioned to an intuitive gesture-based system that simplified interactions to lifting, holding, and placing the statue.

This final interaction design, as illustrated in this section, eliminates the complexity of story selection and removes the need for users to train with VR controllers. Picking up the Sankofa initiates a story, holding it continues the narrative, and placing it down pauses or stops the VR experience. This tangible interaction approach enhances accessibility, particularly for seated users, while minimizing the risk of cyber-sickness and reducing space requirements.

The Sankofa interface embodies the project's goals of fostering an interactive and meaningful experience. Acting as both a symbolic and functional link, the tangible statue tethers users to the physical world while connecting them to the cultural and historical significance of the stories. This connection encourages emotional engagement and self-reflection.

By leveraging the Sankofa's rich symbolism and intuitive functionality, the design positions users as active listeners and witnesses, granting them control over their interaction with the stories. Aligned with the restorative principles of the project, the Sankofa becomes more than just a tool—it serves as a bridge for cultural connection and a medium for fostering awareness, empathy, and engagement.



Figure 5.8: The VR headset begins in passthrough mode with the Sankofa statue sitting on a table (left). The user can pick up the Sankofa to begin the experience. When they pick up the Sankofa, it vibrates with a greeting while the headset remains in passthrough mode (right). This introduces the user to the idea that the Sankofa will vibrate, and situates the Sankofa statue in the physical environment, not part of the virtual experience. This step may coincide with onboarding from a facilitator or on-screen instructions to explain the pick up / place down interaction model and introduce Sankofa.

Interaction Steps involved in Sankofa Interface

The Sankofa interface guides users through various stages of interaction, from initial engagement to the conclusion of the VR experience. Thoughtful design choices throughout these steps enhance the user's emotional connection to the narrative while maintaining their autonomy and grounding in the real world.

I) Initiating the experience by picking up the Sankofa

The interaction design begins with the user positioned in front of a setup equipped with a VR headset and the Sankofa interface. The user first puts on the VR headset, activating passthrough mode, which allows them to see their physical surroundings and the presence of the Sankofa in the real world. This action not only starts the VR experience but also



Figure 5.9: After the introduction and greeting, and after any orientation or instructions, Sankofa renders a vibration representing “let’s listen” (left) as the world transitions to a VR rendered environment (right). The VR experience then begins to play. The user must actively hold the Sankofa interface to play the experience, a physical act of intentional, active listening by holding a weighty object with a great deal of meaning for the VR experience.

serves as a metaphorical gesture, symbolizing the user’s acceptance of the Sankofa and their willingness to listen to the stories it carries.

While the user is still in passthrough mode, vibration for “Hello,” inspired by the White-necked Rockfowl’s audio is generated through the Sankofa to signal that the VR experience is about to begin, as shown in Figure 5.8. The Sankofa interface, combined with haptic feedback, acts as a bridge connecting the real and virtual worlds. The vibrations are intentionally triggered during physical interactions with the Sankofa, tethering the user in the real world and reinforcing both their presence and the Sankofa’s connection to the physical environment outside of VR.[1]

[1]The demo of a user interacting with the Sankofa, including its interaction steps and corresponding vibrations, is available in the short video provided as supplementary material for this paper.

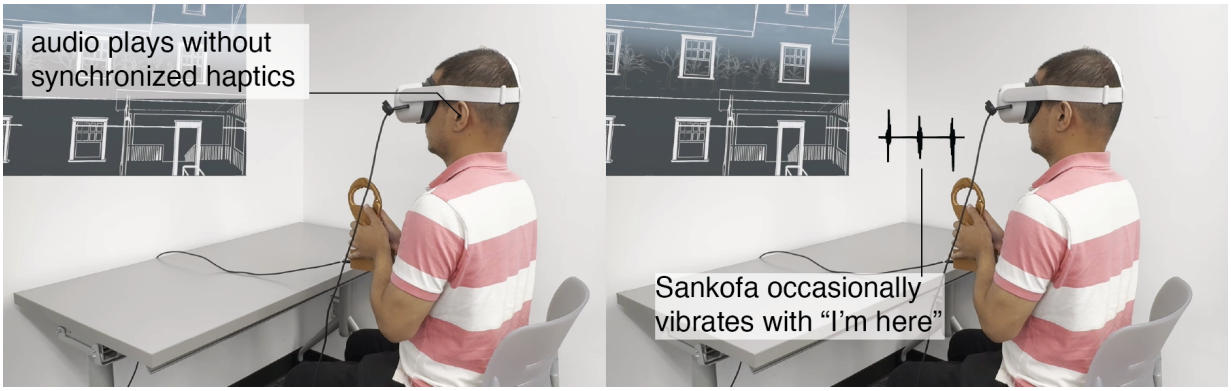


Figure 5.10: As the story plays, the Sankofa statue is not rendered in the virtual environment, reinforcing that it is situated in the physical environment alongside the user, who has no avater (left). Sankofa does not vibrate to reinforce spoken word, music, or sound effects, but instead might vibrate at carefully chosen points to dampen presence and remind the user that they are bearing witness to the story, not participating within it.

II) Shifting to VR Story Mode on the headset

After picking up the Sankofa interface, users experience a gradual transition from passthrough mode to the VR environment, as illustrated in Figure 5.9. During this transition, the “Let’s Listen” vibration pattern is rendered, signaling the official start of the storytelling experience.

To fully engage with the experience, users must actively hold the Sankofa statue—a deliberate and meaningful act of active listening. The weight of the object emphasizes the significance of the VR journey, fostering a deeper emotional connection to the narrative.

In this phase, random VR stories from the DOHR are played, immersing users in a rich and reflective storytelling journey.



Figure 5.11: If the user wishes to stop or exit the experience at any time, they simply place the Sankofa statue down on the table. This will pause the experience and transition the headset into passthrough mode. If left longer than an adjustable timeout duration (e.g., a minute), the experience resets. Because there is no rendered table, statue, or hands in the experience, embedded sensors on the statue (currently infrared distance sensors) detect when it is placed down anywhere on the surface and initiate the transition to passthrough. The statue is further designed to have a large base to easily settle into position.

III) Embracing relational presence in VR using Haptic Feedback

While users experience VR stories from the DOHR, the Sankofa interface occasionally generates haptic feedback in the form of the "I'm here" vibrational pattern. These vibrations are deliberately not synchronized with the narrator's voice in the stories. This intentional design dampens the re-embodiment process in VR, subtly reminding users of their presence in a safe, physical space. Additionally, this feedback reinforces users' autonomy, providing a continuous sense of control and emphasizing that they can terminate the VR experience at any moment if they so choose.

IV) Placing down the the Sankofa to pause or exit the session

In this VR experience, users have the option to pause or completely stop the experience at any time by setting down the Sankofa. Given that the narratives within the experience address topics that may be uncomfortable for some users, this feature allows individuals to take breaks or abruptly terminate the experience as needed. Resuming the story is as simple as picking up the Sankofa again.

At the end, the act of placing the Sankofa down signifies the user's exit from the VR experience. This gesture symbolizes not only the acquisition of knowledge but also the passing of the Sankofa's essence to the subsequent user.

5.3.4 Discussion

In this section, we synthesize and extend insights emerging from our interdisciplinary, community-driven co-design of the Sankofa interface. These insights illuminate the nuanced complexities of designing VR and haptic experiences guided by restorative justice principles and highlight essential considerations for similar design collaborations.

I) Relational Presence Reframes Immersion

Traditional VR design typically equates presence with deep sensory immersion, emphasizing interactivity, fidelity, and user agency to produce the illusion of "being there" [513]. In contrast, our project adopts "relational presence," shifting the core goal from immersion to ethical engagement grounded in restorative justice. Relational presence emphasizes witnessing and reflective awareness, enabling participants to actively listen, consider others'

perspectives, and remain connected to their real-world contexts, thus supporting critical reflection, self-awareness, and affective dissonance rather than allowing users to lose themselves entirely in virtual narratives [451, 333].

VR experience with the Haptic Sankofa provides vibrational feedback during different interval of the VR experience which tries to deliberately temper the level of sensory immersion to ensure participants remained tethered to their physical reality and emotional safety while engaging with difficult historical narratives. This reframing of immersion aligns with calls for more ethical, pedagogy-led VR design in HCI. The designs that privilege critical reflection and empathy over escapism.

By orienting the experience toward relational presence, we followed restorative justice principles (e.g., active listening, mutual respect) in the medium of VR. Our approach thus contributes to an emerging paradigm in HCI and VR where immersive presence is not the only goal; instead, relational presence becomes a means to foster understanding, accountability, and human connection in virtual experiences. Also, we introduce a strategy that hapticians can use to strategically dampen or mediate immersion. In our case, it was via subtle haptic "check-ins", to support users as reflective witnesses rather than uncritical participants, ultimately enriching the ethical and educational impact of VR storytelling.

II) Symbolic Artifact as Catalysts for Design Dialogue

Our co-design process leveraged the Sankofa statue—a culturally significant artifact—as a powerful catalyst for dialogue among collaborators. In restorative practices, a shared "talking piece" symbolizes respect and turn-taking, helping participants build trust and share personal narratives. Consistent with these principles, the physical Sankofa sculpture

was adopted by the DOHR team (and subsequently by our design group) as a talking piece during in-person sharing circles. This symbolic object carried deep meaning, immediately grounding our design conversations in the project's cultural and emotional context. Functioning as a classic boundary object [246], the Sankofa artifact served as a common reference point for collaborators - such as community storytellers, technologists, and educators—who each interpreted it uniquely, yet found convergence in its symbolic resonance. Previous research emphasizes how boundary objects effectively bridge knowledge gaps, embody abstract concepts tangibly, and facilitate clear communication among diverse stakeholders.

Our co-design workshops confirmed this power: for instance, in an early session, the haptics team brought multiple Sankofa artifacts (including wooden carvings and early 3D prints), placing them on the table for everyone to handle and discuss. The mere presence of these symbolic objects sparked rich conversation and storytelling. Collaborators openly shared personal interpretations of Sankofa's significance, debated how the artifact's physical form could mediate meaningful interactions within the VR experience, and spontaneously utilized it to physically enact imagined interactions (e.g., lifting the statue to indicate willingness to listen). Symbolic artifacts have previously been shown to lower barriers for participation, giving designers (especially those new to design processes) - a way to externalize intangible ideas and feelings that might otherwise be difficult to express purely through language.

Furthermore, the Sankofa artifact's cultural resonance strongly influenced key design decisions. Through iterative co-design sessions, the Sankofa interface surfaced as the leading concept, eclipsing alternative design ideas such as candles or abstract shapes. Its metaphor-

ical depth was consistently highlighted as an essential component that "felt right" for the gravity of the narratives shared in VR. Participants recognized Sankofa's significant interaction potential (e.g. touching, lifting, experiencing vibration), all of which naturally aligned with its symbolic meaning. Integrating a symbolic artifact not only honored the restorative justice context but also became a conversational anchor, fostering empathy, focusing creative discussions, and ensuring that technological choices remained intimately woven into cultural narratives. This experience reinforces HCI literature highlighting the ability of meaningful material "things" to profoundly catalyze dialogue, empathy, and creative co-ideation.

III) Situated Co-Design Enhances Collaborative Imaginations

Our project highlights how situating co-design activities in real community settings and directly engaging communities enhances participants' collaborative imagination. Rather than conducting our design workshops in detached lab environments or abstract locations, we purposefully hosted key sessions at meaningful, community-relevant sites. For instance, idea generation was held in Halifax, near where our storytellers reside, and included a visit to the historical museum where the VR experience will ultimately be presented. This visit was intentionally structured to allow our team to become familiarized with the local history and setting that would directly inform the VR narratives.

Early in our design process we organised a one-day, on-site workshop that combined technical ideation with relationship building in the project's community and historical setting. Community members guided the haptics team through the museum to absorb its spatial cues and emotional resonance. Conducting these activities in situ proved invalu-

able, as the designers gained crucial insights from both spatial and emotional aspects of the museum environment, which directly informed their design considerations and sparked contextually grounded ideas. The broader co-design literature supports the notion that creativity is fundamentally a collective, contextual act, thriving best when deeply connected to the lived experience and real contexts of participants [474]. By framing co-design explicitly as a process of joint exploration in authentic community spaces, we created opportunities for collaborators to draw on local knowledge, collective memory, and sensory experiences, enriching their shared imagination of design possibilities.

During this situated workshop, many initial design ideas emerged organically through discussions driven by context. For instance, the idea of incorporating physical lighting rituals, such as lighting candles representing themes of hope or remembrance, surfaced directly from dialogue inspired by the museum environment and potential VR storytelling scenarios. Similarly, during conversations grounded in the storytellers' experiences, a collaborator highlighted the significance of a particular "rock" frequently featured in DOHR VR stories. This insight inspired the design concept of incorporating a tangible "grounding rock", placed beneath users' feet to enhance a sense of comfort and connection in the VR experience. Additionally, engaging participants in collaborative imagining of VR narrative scenarios proved especially effective in such contextual sessions. As collaborators collectively recalled specific historical events or community experiences, they jointly envisioned how haptic feedback or visual enhancements could naturally become integral components of these narrative moments. Being physically and socially present together provoked new ideas in one another through shared situated experiences [90].

IV) Trust Building through Tangible Collaboration

We found that trust and mutual understanding within our interdisciplinary team community storytellers formed the foundation for successful co-design. Many collaborators had previously spent significant time working together to create the DOHR VR experience, whereas the haptics team was new to this established group. Tangible materials and hands-on interactions proved instrumental in bridging this gap and deepening interpersonal trust. Participatory design and restorative justice literature similarly highlight the importance of creating safe and equitable spaces, stressing that participants must feel respected, heard, and actively supported to authentically engage in collaborative innovation [613].

At the beginning of our project, natural barriers existed: community storytellers brought personal experiences linked to sensitive subject matter and trauma; haptics team, meanwhile, were entering a sensitive, culturally unfamiliar context. To intentionally bridge these gaps, our initial meetings prioritized relationship-building over immediate feature generation. Our very first in-person workshop emphasized sharing personal stories, communal meals, and getting to know each other personally. We integrated a restorative justice process by beginning in a circle, using the culturally meaningful Sankofa statue as a talking piece, inviting participants to openly express their hopes, concerns and expectations for the project. This structured openness created an atmosphere of mutual respect and active listening, effectively setting the stage for deeper collaboration.

Working with tangible artifacts further cultivated trust, as physical co-creation helped offset abstract hierarchies or expertise gaps. Rather than theoretical debates between technical and non-technical participants, conversations centered naturally around shared phys-

ical objects—prototypes, sketches, demo devices, and symbolic materials—which everyone could intuitively manipulate and explore together. Tangible co-creation is known in participatory design and HCI literature to lower barriers for participation, facilitating inclusive, face-to-face engagement [232]. We observed directly how community members who initially hesitated to participate became more comfortable once physically interacting with prototypes (e.g holding haptic prototype devices, providing tactile feedback). Overall, Hands-on collaboration reinforced collective ownership and confidence.

Moreover, culturally resonant artifacts such as the Sankofa statue further enhanced trust-building. As a symbol of community resilience and history, the statue physically manifested the storytellers' heritage and values, reassuring them that their core principles and cultural identity were explicitly honored within the design.

Ultimately, trust-building through tangible collaboration was not merely incidental but deliberately central to our co-design approach. By integrating participatory design techniques and restorative justice principles such as introductory circles, shared cultural symbols, and hands-on activities, we nurtured an environment in which every voice felt genuinely valued. This trust encouraged open communication and constructive feedback, allowing honest acknowledgment when prototypes did not align with expectations, and ultimately led to more robust and meaningful collaborative outcomes.

V) From Shared Vocabulary to Shared Ethical Commitments

Given the multidisciplinary composition of our team, establishing a shared vocabulary was a critical first step in our collaborative process. Early on, differences in technical terminology became apparent: engineers' language around concepts such as "haptic feedback,"

"immersion," and "motors" appeared opaque to non-technical collaborators, while terms like "relational presence" or "restorative justice" required translation for team members newer to justice pedagogy. To bridge these gaps, we intentionally created opportunities for bidirectional learning across disciplines. Engineers translated specialized haptics terms into accessible experiential descriptions using tangible demonstrations and familiar analogies from everyday experiences, such as mobile phone vibrations and gaming interactions, while restorative justice practitioners shared narratives and principles grounding technological efforts within lived community experiences. Such reciprocal learning aligns closely with prior HCI and participatory design research advocating for inclusive, hybrid "third spaces," where shared meanings co-emerge through dialogue, prompting stakeholders to question assumptions and engage in mutual understanding [213]. This iterative translation of specialized language into an accessible, shared vocabulary fostered mutual respect and built the foundation for effective co-design.

Yet, developing a shared vocabulary served only as the foundation. Genuine collaboration within our justice-oriented project required moving beyond simply speaking a common language, toward explicitly embracing shared ethical commitments. Each collaborator brought unique professional ethics and personal stakes to the table, ranging from an engineer's commitment to safety, an educator's focus on learning outcomes, to a community member's dedication to honoring lived experience. Aligning these diverse perspectives around restorative justice principles became a deliberate and central aspect of our discussions. Dombrowski et al. [137] framework for social justice interaction design, for example, emphasizes reflexivity and personal ethics as crucial safeguards against inadvertently reproducing harmful power imbalances. In line with these insights, our entire team

explicitly committed to centering storytellers' "first voices" and maintaining a restorative ethic of "doing no further harm". Principles such as accountability, equal partnership, and reciprocity were recognized not as abstract ideals, but as practical design guidelines. For instance, we collectively chose to omit certain voice-to-haptic effects, candle prototypes, the 2D Sankofa design, and other design elements mentioned in subsection 5.3.2 from our haptic feedback implementation, out of respect for the integrity of the narratives. We also regularly paused our development process to reflect on whether our decisions honored or undermined these restorative principles.

Our experiences confirm emerging arguments in HCI calling for design processes grounded not only in a shared vocabulary but also in shared ethical responsibility and intentionality [216]. Moving deliberately from common language to shared ethical commitments allowed us to make design decisions guided by a unified moral compass, ensuring our technology ultimately remained accountable to and aligned with the community's restorative vision and commitment to justice.

VI) Acknowledging Emotional Labour in Restorative Design

Engaging with a project centered on historical trauma and restorative justice demanded significant emotional labour from everyone involved. From storytellers who courageously relived and shared their experiences, to researchers who bore witness to these narratives, the process was emotionally intense. We quickly recognized that restorative design is not merely a technical or creative undertaking - it is inherently affective, necessitating intentional care for the emotional wellbeing of all participants and team members.

Recent HCI discussions emphasize that researchers in sensitive, justice-focused contexts

often undertake substantial emotional work and face moral dilemmas, yet this labour is rarely acknowledged [207]. To counteract this omission, our team deliberately normalized and openly acknowledged the emotional toll the project could exert. For example, we organized structured debrief sessions following each co-design workshop, allowing team members to share feelings and process emotional reactions. Additionally, we explicitly encouraged and normalized self-care practices (such as taking breaks or temporarily stepping back from difficult discussions). These strategies align closely with ongoing movements in HCI advocating affective reflexivity and deliberate attentiveness toward researcher wellbeing, especially when dealing with experiences of trauma or marginalization [207].

Critically, acknowledging emotional labour also involved thoughtfully accommodating the emotional and epistemic burdens placed upon our community co-designers. Participatory projects with marginalized participants can unintentionally impose heavy emotional demands and expectations on individuals sharing challenging lived experiences [26]. Our community storytellers were not merely participants; they were active co-design partners whose contributions represented irreplaceable emotional and intellectual efforts. Without careful consideration and structures of genuine support, participatory methods risk exploiting these personal narratives and emotional commitments [147]. To navigate this risk, we carefully paced the design process to respect community partners' readiness, encouraged them to articulate boundaries around sharing sensitive knowledge, and continuously checked consent at each stage of narrative integration. This proactive stance corresponds closely with emerging principles of trauma-informed design within HCI practice, which emphasizes minimizing re-traumatization and safeguarding participants' agency over their stories [492].

The subsection 5.3.3 shows our design translated restorative principles into tangible interface features, such as the integration of an emergency stop gesture - placing down the Sankofa object to immediately pause or exit the VR experience. Providing this control mechanism directly acknowledges the emotional intensity of engaging with difficult memories, mirroring similar strategies adopted in other trauma-informed HCI projects designed to ensure users have mechanisms to regain comfort and autonomy amid emotional discomfort [102].

VII) Synchronizing Multidisciplinary Work Rhythms

One of the key challenge was reconciling different work rhythms and expectations among team members. Some collaborators, particularly those engaging directly with storytellers, were oriented toward longer timelines, thoughtful reflection, and relationship-building. In contrast, the haptics team often sought more immediate feedback on designs and prototypes within structured development cycles. Prior research acknowledges that varying tempos and incentive structures can generate interpersonal tensions within multidisciplinary teams, requiring deliberate strategies and coordination efforts [137].

We addressed these differences by establishing transparent channels of communication, holding regular cross-team check-ins, and cultivating an explicit culture of patience and compromise. When potential conflicts arose - such as publication deadlines coinciding with urgent community event preparations, the group collectively prioritized decisions closely aligned with our restorative mission, intentionally respecting everyone's timing, constraints, and contributions.

Additionally, synchronizing our diverse rhythms meant bridging distinct goals among

collaborators. The haptics team aimed to distill project insights into both theoretical contributions and tangible outputs (e.g prototypes), whereas our collaborators prioritized careful relationship-building and ongoing engagement with storytellers. We addressed these differences by frequently sharing updates and maintaining open communication through emails, online meetings, and in-person discussions, ensuring each group's workflow remained aligned and mutually supportive. This approach resonates strongly with contemporary HCI literature emphasizing reciprocal partnerships that simultaneously value theoretical rigor, tangible outcomes, and meaningful community relationships [216].

In summary, effectively synchronizing multidisciplinary work rhythms and collaborative efforts demanded intentional strategies grounded in active listening, flexible scheduling, open negotiation, and dual dissemination practices.

5.4 Discussion

Synthesizing insights from both the structured CHI collaborative workshop and the community-driven Sankofa co-design (chapter 4), we identified crucial empirical guidance for improving multidisciplinary collaboration in haptic design contexts. We highlight seven central interconnected areas crucial for effective collaborative practice:

5.4.1 Coordination: Clear Role Definition and Balanced Responsibilities

Participants consistently highlighted the challenges of unclear roles and responsibilities, as evidenced by low survey ratings on *Role Clarity* (Figure 4.4) and early struggles expressed qualitatively ("It was hard to know who was supposed to do what"). Our earlier Sankofa project experience mirrored these challenges, emphasizing that explicitly clarifying roles and balancing responsibilities based on disciplinary expertise was critical (subsubsection 5.3.4). Without clarity, role ambiguity significantly disrupted productivity, reinforcing prior literature identifying role ambiguity as a persistent obstacle to effective interdisciplinary communication and integration [482]. Documenting team members' backgrounds and explicitly defining disciplinary roles thus appears essential to harnessing collaborative diversity.

5.4.2 Trust: Tangible Artifacts as Collaborative Bridges

Tangible collaborative processes - such as physical prototyping, iterative sketching, and collaborative hands-on sessions—consistently fostered relational trust across both project contexts [232]. Participants in Part II strongly valued the informal and tangible approach ("playing around with components"), which parallels our application of tangible symbolic artifacts like the Sankofa statue in Part I (subsubsection 5.3.4). Specifically, tangible artifacts acted as powerful "boundary objects " [246], aligning diverse perspectives and facilitating dialogue across disciplines and experiences (subsubsection 5.3.4). Such physical

engagement provided transparency, enabled mutual understanding, and fostered relational presence, especially pertinent within sensitive restorative justice contexts.

5.4.3 Communication: Establishing Common Language and Visual Documentation

Across both studies, effective communication consistently hinged on establishing a shared vocabulary and clear documentation. Surveyed teams frequently resorted to informal verbal communication but noted substantial difficulties translating fleeting discussions into action, emphasizing the critical necessity of visual documentation (sketches, diagrams) to concretize ideas (subsubsection 4.1.4). In Part I, the creation of a collaborative "third space" [213] and explicitly defining restorative justice-related terms (e.g "relational presence") and technical words significantly reduced misunderstandings and empowered multidisciplinary integration (subsubsection 5.3.4). Consistent co-created visual and written records thus effectively bridged disciplinary divides in both technical prototyping and ethically nuanced design scenarios.

5.4.4 Technical Competency: Shared Haptic Literacy Through Experiential Training

Addressing shared haptic literacy emerged from both studies as vital for meaningful multidisciplinary collaboration. Initially distinct technical vocabularies created communication barriers; structured and experiential haptic literacy training helped bridge these knowledge gaps (subsubsection 5.3.4). Participants specifically called for grounded experiential inter-

actions, simpler initial explanations ("basic explanations not assuming prior knowledge"), and better accessibility of toolkit hardware, underscoring how early technical encounters democratically engaged all collaborators. Context-sensitive and experiential training sessions to democratize multidisciplinary design dialogues.

5.4.5 Negotiation: Structured Processes for Addressing Multidisciplinary Tensions

Multidisciplinary disagreements inevitably arose across both project contexts. Participants strongly emphasized structured negotiation procedures—explicit checkpoints, facilitated discussions, formal design reviews—as essential practices for constructively reconciling disciplinary differences, as identified in both Part I and Part II (subsubsection 5.3.4). Explicitly negotiating priorities and aligning workflows proved critical, balancing differing disciplinary tempos, underlying values, and ethical concerns. These structured processes provided a transparent forum for creatively integrating diverse technical, educational, and ethical viewpoints into cohesive design outcomes [482].

5.4.6 Ownership: Collective Accountability and Shared Artifacts

Establishing shared ownership emerged strongly throughout. Joint documentation and collective authorship of design logs, requirement documents, and artifacts solidified collective project accountability. Symbolic artifacts, such as the Sankofa statue (subsubsection 5.3.4), enhanced team unity by physically and emotionally grounding collective responsibilities. Shared documentation practices explicitly translating collaborative ideals

into actionable routines reinforced cohesive collaborative experiences and strengthened interpersonal bonds.

5.5 Conclusion

This chapter explored collaborative practices and associated challenges within two multidisciplinary contexts: the Sankofa Project co-design initiative.

The key findings emphasized the value of situated co-design in authentic community settings, the importance of establishing shared haptic literacy through experiential hands-on activities, and the significance of tangible prototypes as boundary objects to facilitate mutual understanding. Additionally, we found explicit acknowledgment of emotional labour, ethical alignment, and proactive synchronization of diverse work rhythms essential to maintaining trust, emotional well-being, and reflective practice throughout the collaboration.

Together, insights from both contexts contribute practical directions and essential considerations for future interdisciplinary collaborations in haptics and justice-oriented HCI research, emphasizing careful attention to situated contexts, clearly articulated roles, accessible communication, shared technical grounding, and ethical reflexivity.

Chapter 6

Confirmation: Evaluation of Haptic Systems

Although user-centered research in haptics is a growing, evaluation methods in haptics remain highly fragmented and inconsistently reported, hindering comparison, replication, and progress across the field [482]. Yet a major gap remains across both research and design practice: the lack of standardized and consistent methods for evaluating haptic experiences. Prior work has identified significant inconsistencies in how such evaluations are conceptualized and conducted. Kim and Schneider [284] found that hapticians often rely on ad hoc, self-developed tools, making it difficult to compare findings across studies. Dalsgaard and Schneider [123] reviewed 104 studies and found that most evaluations defaulted to usability plus one other construct, overlooking deeper hedonic and eudaimonic qualities.

A recently proposed solution—the HXI [500] offers the first standardized questionnaire for touch feedback and signals growing momentum toward shared metrics. Yet HXI is

still new, its adoption limited, and it addresses only the subjective layer of evaluation. Pragmatic questions remain unanswered: what evaluation metrics do haptic practitioners currently employ, how are these metrics adapted across different application domains, and which best-practice procedures can be extended to areas such as wearables, VR, and affective haptics to establish a reliable evaluation workflow? To establish concrete guidelines for haptics assessment, we must first map the current landscape to identifying what is measured, how, and why, so that emerging tools like HXI can be integrated into coherent, field-wide best practices.

To address this gap, we present a scoping review of peer-reviewed papers that evaluate haptic devices through empirical user studies. Drawing on articles from CHI, UIST, World Haptics, and related venues indexed in IEEE Xplore and the ACM Digital Library, we map the methods used to assess haptic technology, the audiences they serve, the factors and metrics they report, and the hardware and software they employ. Our analysis compares these elements across studies to uncover common patterns, persistent gaps, and the role of context, then translates these findings into practical guidance for researchers and designers. The review contributes two outcomes: a structured corpus of haptic-evaluation studies, and a set of evidence-based recommendations that can guide future work toward more consistent and comparable evaluation practice.

6.1 Methodology

The protocol follows the JBI Scoping Review Guidelines [255] and was designed to support a comprehensive and systematic exploration of evaluation practices in haptics research.

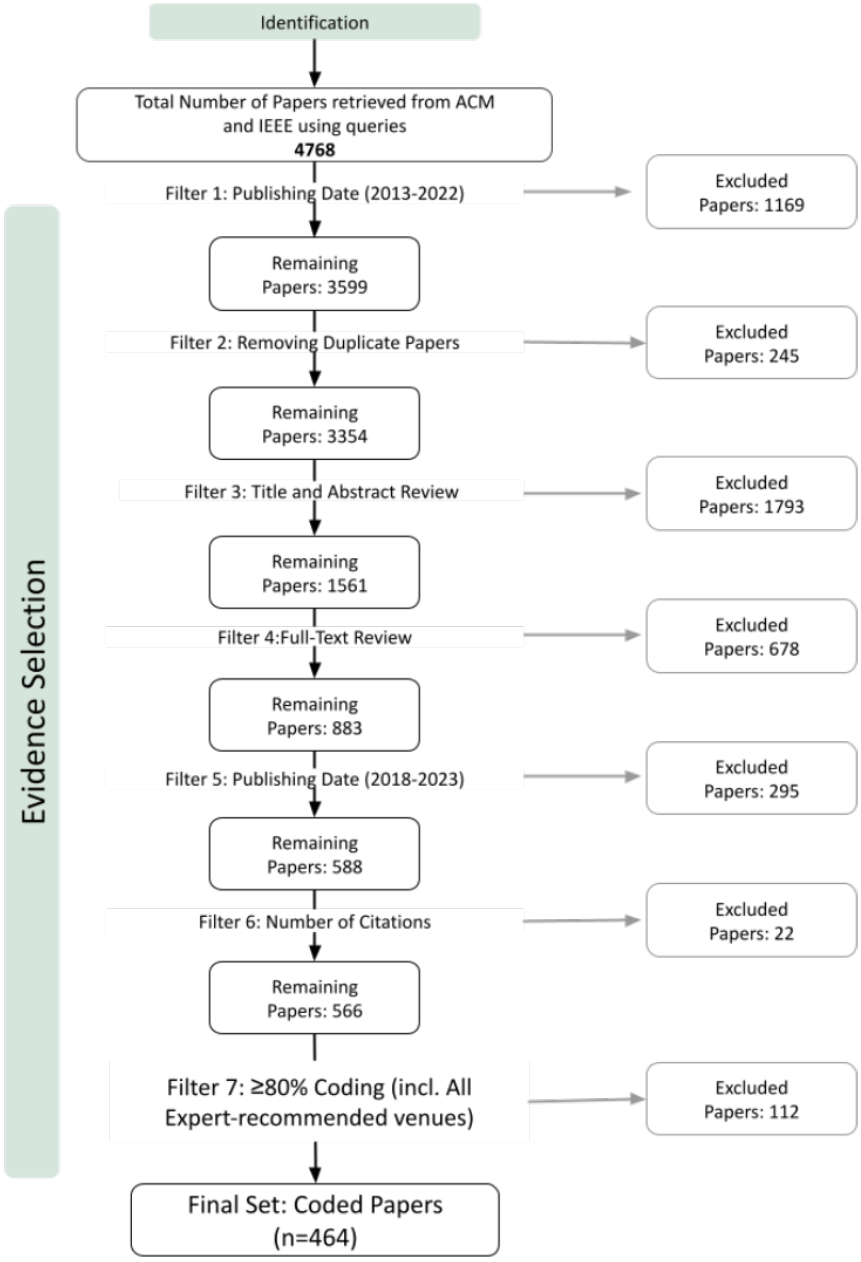


Figure 6.1: Flow Diagram displaying methodology used to obtain final corpus used for scoping review evidence. A total of 4,768 papers were screened through seven filters, resulting in a final coded set of 464 papers.

We conducted structured searches in two digital libraries - ACM Digital Library and IEEE Xplore, using a keyword-based query designed to capture studies that discuss haptic technologies and include some form of user evaluation.

As shown in Table 6.1, the query consisted of three parts: (A) haptics-related terms; (B) evaluation- or user-focused terms; and (C) a publication date filter spanning 2013 to 2023. The initial search conducted on 12 May 2023, returned 4,768 records across both databases. We applied additional filters to retain only research articles (ACM: "Research Articles"; IEEE: "Journals" and "Conference Papers"), and limited the inclusion of terms to the title, abstract, or keywords.

Query construction

- Part A: "touch" OR "haptic" OR "haptics" OR "kinaes" OR "tactile"
- Part B: (("user*" OR "participant*" OR "pilot") OR ("evaluat*" OR "validat*" OR "study" OR "experience" OR "ux" OR usability))
- Part C: From 2013 to 2023

6.1.1 Data Extraction and Coding

Figure 6.1 traces our multi-stage screening workflow. Using Airtable to store all records and log reviewer decisions, we began with 4,768 records, we sequentially applied seven filters - date, duplicates, title/abstract, full-text, updated date, citation count, and 80 % coder agreement to reach a final corpus of 464 papers. Title/abstract screening was double-coded

Database	Search String	Results
ACM Digital Library	Abstract:((”touch” OR “haptic” OR “haptics” OR “kinaes*” OR “tactile”) AND ((”user*” OR “participant*” OR “pilot”) AND (”evaluat*” OR “validation” OR “experience*” OR “study” OR “usability” OR “ux”))) OR Keyword:((”touch” OR “haptic” OR “haptics” OR “kinaes*” OR “tactile”) AND ((”user*” OR “participant*” OR “pilot”) AND (”evaluat*” OR “validation” OR “experience*” OR “study” OR “usability” OR “ux”))) OR Title:((”touch” OR “haptic” OR “haptics” OR “kinaes*” OR “tactile”) AND ((”user*” OR “participant*” OR “pilot”) AND (”evaluat*” OR “validation” OR “experience*” OR “study” OR “usability” OR “ux”)))	2449
IEEE Xplore Digital Library	[((”Abstract”:”touch” OR “Abstract”:”haptic” OR “Abstract”:”haptics” OR “Abstract”:”kinaes*” OR “Abstract”:”tactile”) AND ((”Abstract”:”user” OR “Abstract”:”participant” OR “Abstract”:”participants” OR “Abstract”:”pilot”) AND (”Abstract”:”evaluat*” OR “Abstract”:”validation” OR “Abstract”:”study” OR “Abstract”:”experience” OR “Abstract”:”usability” OR “Abstract”:”ux”))) OR ((”Author Keywords”:”touch” OR “Author Keywords”:”haptic” OR “Author Keywords”:”haptics” OR “Author Keywords”:”kinaes*” OR “Author Keywords”:”tactile”) AND ((”Author Keywords”:”user” OR “Author Keywords”:”participant” OR “Abstract”:”participants” OR “Author Keywords”:”pilot”) AND (”Author Keywords”:”evaluat*” OR “Author Keywords”:”validation” OR “Author Keywords”:”study” OR “Author Keywords”:”experience” OR “Author Keywords”:”usability” OR “Author Keywords”:”ux”))) OR ((”Publication Title”:”touch” OR “Publication Title”:”haptic” OR “Publication Title”:”haptics” OR “Publication Title”:”kinaes*” OR “Publication Title”:”tactile”) AND ((”Publication Title”:”user” OR “Publication Title”:”participant” OR “Abstract”:”participants” OR “Publication Title”:”pilot”) AND (”Publication Title”:”evaluat*” OR “Publication Title”:”validation” OR “Publication Title”:”study” OR “Publication Title”:”experience” OR “Publication Title”:”usability” OR “Publication Title”:”ux”)))]	2319

Table 6.1: Search queries used in ACM and IEEE Digital Library (executed on May 12, 2023), along with the number of results returned. Filters applied included: (1) research articles only, (2) keyword appearance in title, abstract, or keywords, and (3) publication date between 2013 and May 2023.

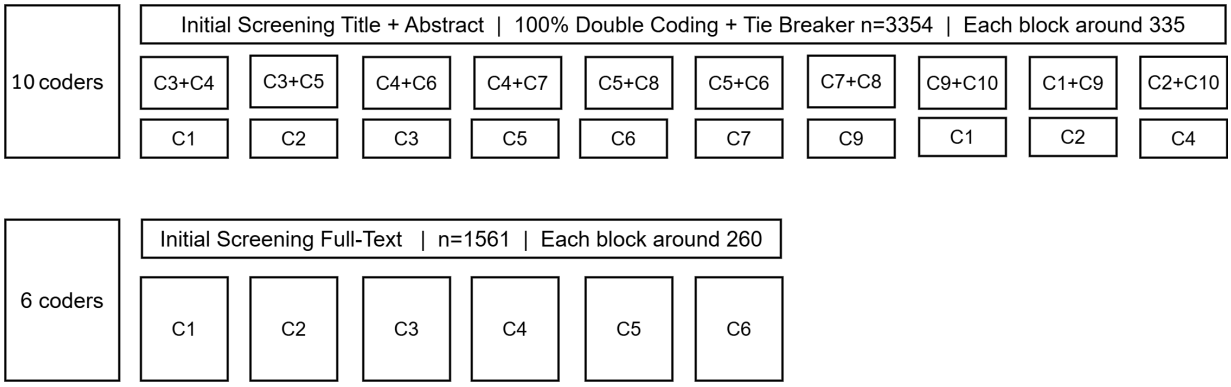


Figure 6.2: Coder allocation across screening stages. Top row: eight reviewers double-coded the 3,354 title-and-abstract records in blocks of about 335 papers, with a third coder acting as tie-breaker. Bottom row: six reviewers then single-coded the 1,561 papers that advanced to full-text screening, each handling roughly 260 papers.

by eight reviewers, full-text eligibility by six, and final in-depth coding by five, with each phase divided into equal blocks for load balancing as shown in Figure 6.2 and Figure 6.3. The diagram therefore summarizes both the attrition of papers and the allocation of coder effort.

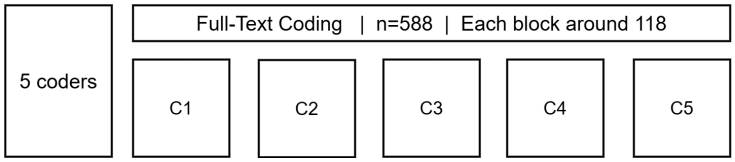


Figure 6.3: Coder allocation during the full-text coding phase: five coders (C1–C5) each reviewed approximately 118 of the 588 remaining papers.

To support the screening and data extraction process, ten graduate and undergraduate students from the Haptic Experience Lab participated as coders. The review process followed the JBI Scoping Review Guidelines [255] and used a double-screening protocol during the Title and Abstract Review stage to minimize individual bias. Each paper in that stage

was independently reviewed by two coders, with disagreements resolved through discussion or a third tie-breaker. All other stages, including full-text screening and coding were conducted by a single coder per paper due to the large volume and resource constraints.

We extracted data related to evaluation design and implementation, including participant demographics, study procedures, study duration, environment setup, body location of haptic stimuli, keywords, technologies used, publication year, and evaluation metrics. The full protocol was preregistered on the Open Science Framework (OSF) and is available at Haptic Evaluation Protocol.

The evidence selection involved seven sequential filters:

1. **Publishing Date (2013–2022):** We first filtered papers by publication year, retaining those published between 2013 and 2022 to reflect recent developments in haptic technology. This reduced the dataset from 4,768 to 3,599 papers.

2. **Duplicate Removal:** Duplicate records were identified and removed using a combination of Zotero's built-in duplicate detection and a custom Python script. Zotero helped identify exact and near-exact duplicates based on metadata, while the Python script compared titles and publication years across BibTeX files from ACM and IEEE to catch remaining redundancies. After deduplication, 3,354 unique papers remained.

3. **Title and Abstract Review:** The 3,354 papers were distributed among ten reviewers (C1–C10). Each paper was reviewed by two independent coders and labeled as `INCLUDE`, `EXCLUDE`, or `UNCERTAIN`. Inclusion criteria required that papers report on peer-reviewed empirical studies involving haptic technology and human participants, written in English, with replicable methods. Papers such as demos, work-in-progress

posters, or those lacking evaluation were excluded. Disagreements were resolved by a third reviewer. This step resulted in 1,561 papers.

4. **Full-Text Review:** Full-text screening was performed by a single reviewer per paper (C1–C6), due to practical constraints. The same inclusion and exclusion criteria were used to confirm the relevance and methodological transparency of each paper. After this stage, 883 papers remained.

5. **Publishing Date (2018–2023):** A second date filter was applied to limit the corpus to more recent work (2018 onward). This reduced the dataset to 588 papers.

   We restrict our corpus to this five-year span because 2018 marks a confluence of technological, methodological, and societal shifts that reshaped haptics evaluation. Commercially, that year ushered in consumer-grade, high-fidelity platforms—such as the Rift-S/Quest VR headsets and early haptic gloves—and was followed by the LeapMotion–Ultrahaptics merger in 2019 that created *Ultraleap*, consolidating mid-air haptics with robust hand tracking [3, 32]. Methodologically, meta-reviews show that pre-2018 work focused overwhelmingly on hardware performance (>90% of papers), whereas a systematic review of 2018–2020 VR–haptics studies reported 96% of haptic studies evaluated physical factors (performance metrics) and only 78% addressed any experiential qualities [31]. Bibliometric analysis likewise report that the majority of haptic and forcefeedback publications appear after 2020 [237]. Crucially, the 2020–2022 COVID-19 pandemic spurred a wave of studies on remote or touch-deprived interaction — which falls within this window. Limiting our review to2018–2023 thus keeps the dataset manageable, captures important technology and

evaluation practices (including pandemic-driven innovations).

6. **Citation Filter:** To ensure a minimum level of scholarly impact, we applied a citation density threshold. Only papers with a citation rate greater than one citation per year since publication (citations/years since publication > 1) were retained. Citation counts were collected on 15 Nov 2023 from both Semantic Scholar and Crossref, and the higher value was used when the two sources differed. This filter reduced the corpus to 566 papers.

7. **Expert-Recommended Venues:** After the citation filter, 566 papers published in 129 different venues remained. To ensure inclusion of seminal and field-relevant work, we also consulted haptics domain experts. A group of 7 experts were provided with the full list of 129 publication venues represented at this stage and asked to rank them on a scale from 1–10 based on their perceived importance for haptics research. Based on aggregate rankings, we selected the top 10 venues most frequently rated highly. All papers from these top 10 venues were included in the final dataset regardless of coding completeness. Of the 464 papers in the final set, 239 originated from these top-ranked venues.

8. **Coding Completeness (80 %):** Five reviewers (C1–C5) then conducted in-depth extraction on the remaining 464 papers, working in equal blocks of roughly 118 papers each (see Figure 6.3). For each study we captured 25 predefined variables; papers with fewer than 20 fields (80 %) successfully recorded were discarded. Applying this threshold eliminated 112 papers, leaving a final corpus of 464 fully coded studies.

Following a rigorous, JBI-guided scoping review methodology, we systematically nar-

rowed the initial dataset of 4,768 papers to a final set of 464 studies. These papers form the evidence base for our scoping review of empirical evaluation practices in haptics research. Each paper in the final dataset was assigned to a member of the coding team for structured data extraction. Coders extracted a standardized set of metadata, including:

- Publication details (authors, year, venue, country of origin)
- Application area of the haptic technology
- Device characteristics (modality, type, active/passive, commercial availability)
- Study methodology (number and type of studies, ethics approval, study duration, location, and user task)
- Evaluation details (metrics used, study objectives, data analysis methods)
- Participant demographics (age, gender, group characteristics)

The extracted data informed all subsequent analyses of trends, gaps, and evaluation practices in haptics research from 2018 to 2023.

6.2 Overview of the Data

The Figure 6.4 categorizes the data collected during the scoping review into five key sections: (1) **General Information of the Paper**, (2) **System Specification**, (3) **Study Design and Methodology**, (4) **Evaluation**, and (5) **Targeted Population**. Each section captures critical aspects of the research articles analyzed in the review. The General

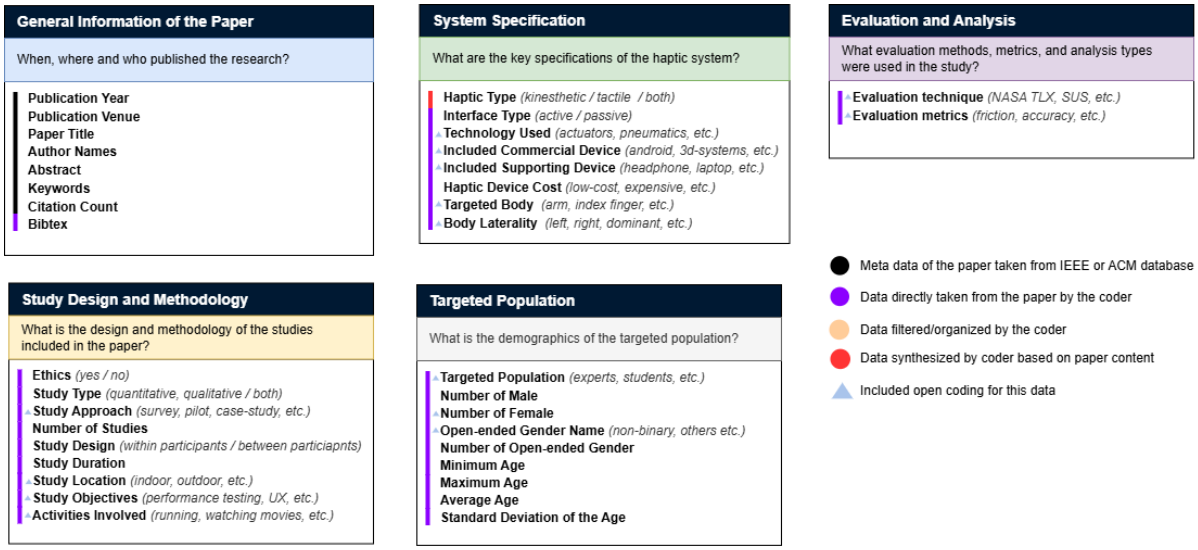


Figure 6.4: Categorization of data collected in the scoping review. The figure organizes the extracted information into five key categories: General Information of the Paper, System Specification, Study Design and Methodology, Evaluation, and Targeted Population. Each category captures specific aspects of the research articles reviewed, such as publication metadata, technological details of haptic systems, study methodologies, evaluation techniques, and participant demographics.

Information category includes bibliographic metadata such as publication year, venue, and author names. The System Specification section focuses on the technological aspects of haptic systems, such as device type, interface type, and cost. The Study Design and Methodology category provides insight into how the studies were conducted, including aspects like study type, objectives, and ethics approval. Evaluation covers the assessment techniques and metrics used in haptics research, while the Targeted Population category details demographic information about study participants.

The data collection process involved multiple sources and methodologies. Some data were extracted directly from IEEE and ACM repositories, while others required manual coding by researchers. Certain elements, such as evaluation techniques and system specifications, were filtered and organized by coders to ensure consistency across studies. In some cases, coders synthesized information from papers to classify ambiguous or underreported data points. The legend in the figure provides a key to understanding the different data sources—metadata extracted from databases, information directly taken from papers, data structured by coders, and synthesized content. The triangle markers (△) indicate areas where open-ended coding was necessary, allowing flexibility in categorization when predefined options were insufficient.

6.3 Results

Our full-text coding analysis yields valuable insights into haptics research, covering target populations, evaluation methods, study designs, and system specifications for empirical studies. The following section presents these findings in detail.

6.3.1 General Trend in data

From 2013 to 2023, topic tags reveal both stable pillars and shifting niches within haptics research as shown in Figure 6.5. “haptic interfaces,” “virtual reality,” and the catch-all “haptics” dominate every year, with notable peaks for interfaces in 2020 to 2021 and for VR in 2022. Tags such as “force,” “visualization,” and “task analysis” appear steadily, reflecting sustained interest in kinesthetic feedback and usability. Other tags surface more sporadically: “rendering,” “robot sensing systems,” and “vibrations” rise and fall without a clear trajectory, while quieter but persistent tags like “training” and “skin” point to specialized yet enduring subfields. These patterns show a core set of concerns continually enriched by new application specific lines of inquiry.

Conference data reinforce this momentum as shown in Figure 6.6. The annual share of haptics papers at the five most active venues climbs sharply after 2016, reaches a high in 2019 to 2020, then stabilizes at a level well above the early decade baseline. Although the roster of top conferences changes over time, several venues appear repeatedly, indicating strong anchor forums for dissemination. This growth, combined with an interdisciplinary mix of conferences spanning HCI, virtual reality, and robotics, signals both expanding community engagement and a maturing ecosystem of outlets that shape and reflect contemporary haptics research.

Figure 6.7 details how the initial literature set was narrowed. During the title and abstract screening stage, the most common exclusion was the absence of an actual haptic experience, followed by lack of human participants and insufficient methodological detail. The full text screening then removed papers that failed to report haptic specific results or

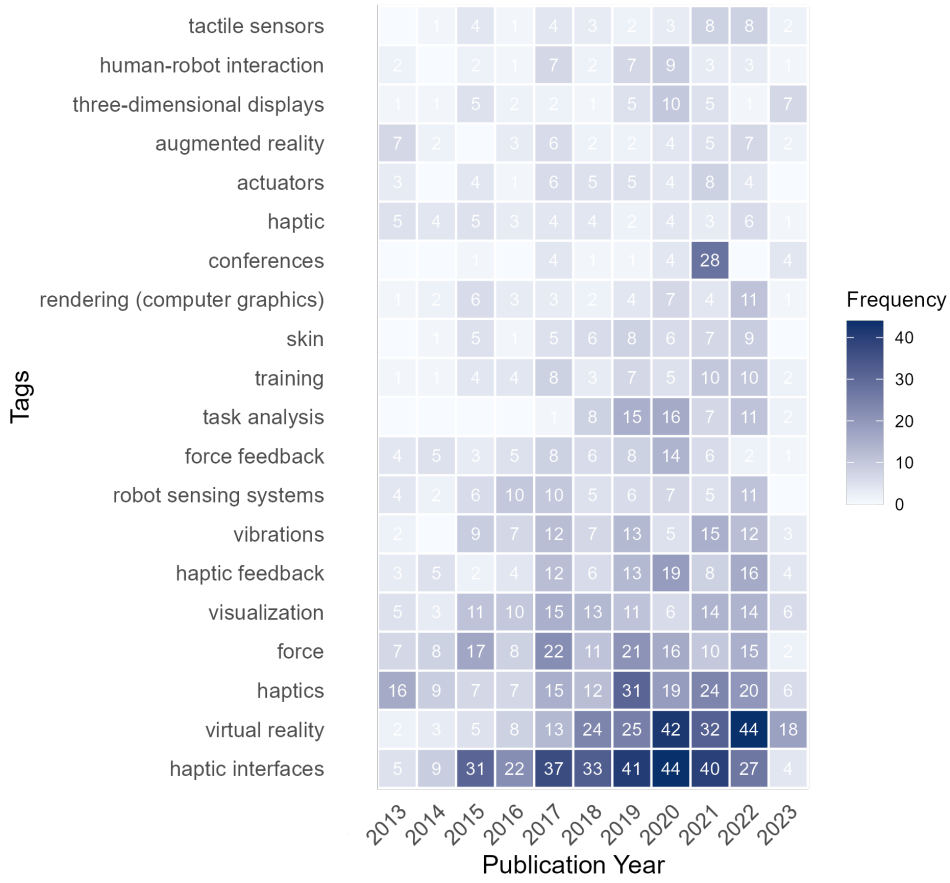


Figure 6.5: Heatmap of Haptic Research Trends (2013-2023): Frequency of research tags such as haptic interfaces, virtual reality, and force feedback over the years, highlighting evolving interests and potential research gaps.

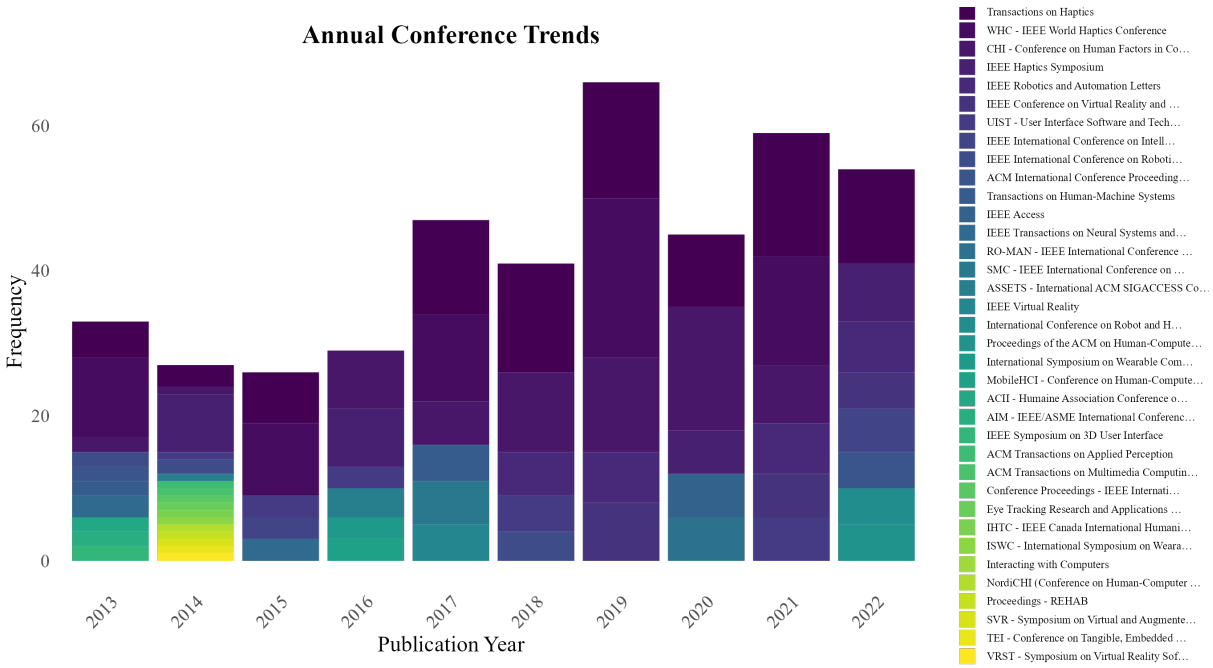


Figure 6.6: Annual Frequency of Top Haptics Conferences (2013-2023)

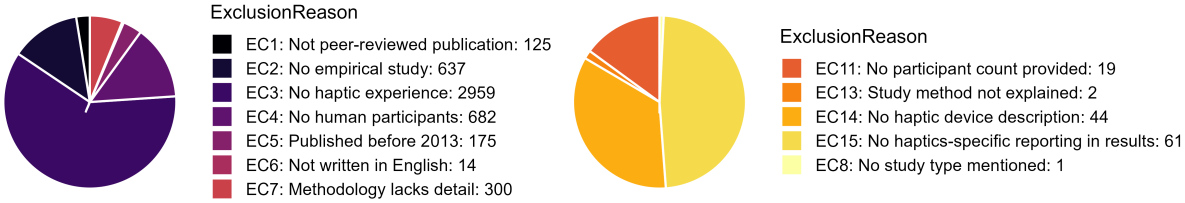
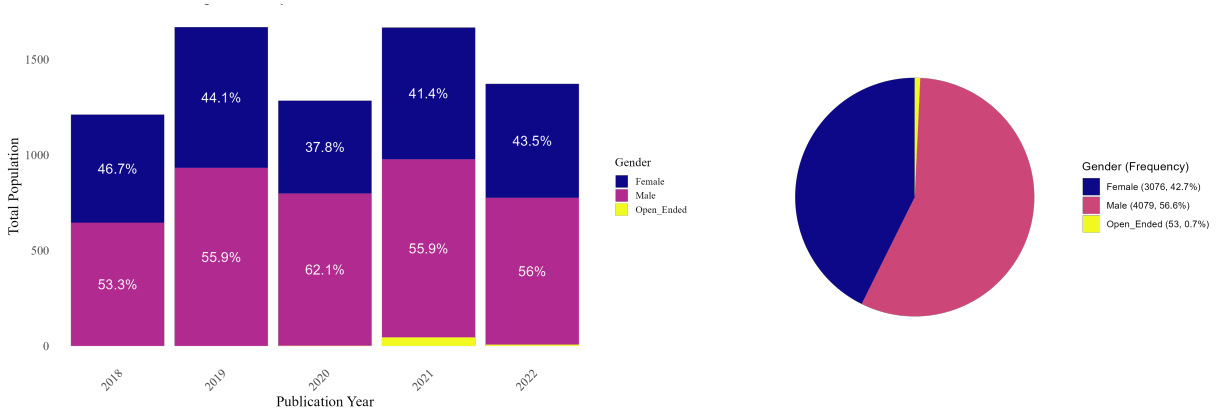


Figure 6.7: Exclusion Criteria for Haptics Research Review



(a) Total participant gender distribution by publication year 2018-2023.

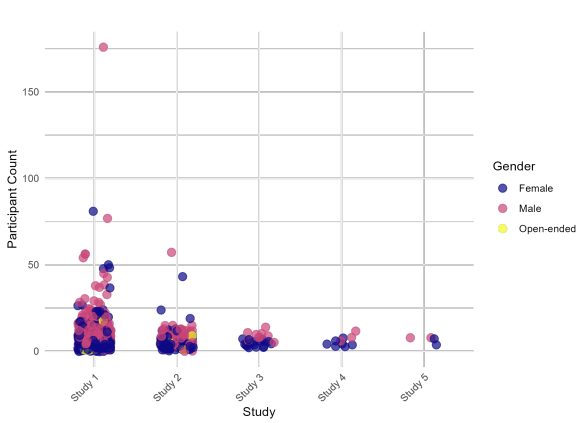
(b) Gender distribution of participants across all studies.

Figure 6.8: Gender distribution of participants. (a) Stacked bar chart showing yearly gender breakdown of study participants from 2018 to 2023, highlighting relative proportions of female, male, and open-ended gender reporting from 2018-2023. (b) Pie chart summarizing the overall gender composition of all participants across the dataset, illustrating the dominance of male participants and minimal open-ended reporting.

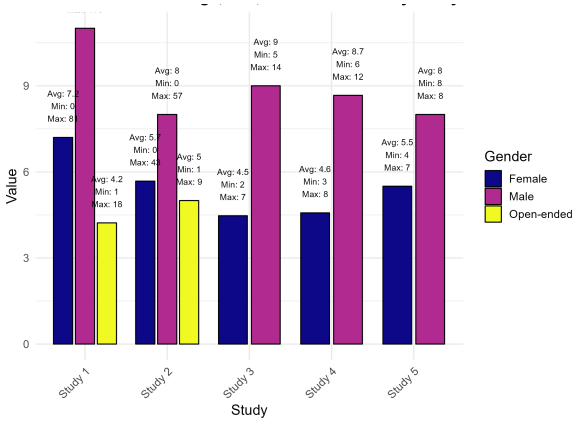
describe the device, along with other reporting gaps. Overall, most exclusions reflected limited relevance, weak empirical grounding, and incomplete reporting, clarifying how the final corpus was distilled to studies with adequate technical, methodological, and experiential substance.

6.3.2 Targeted Population

The target population across reviewed studies highlights distinct trends and notable limitations in demographic representation. As demonstrated in Figure 6.11, the vast majority of studies did not clearly report the demographic characteristics of their participants, severely restricting the transparency and replicability of research findings. Among the demographics



(a) Participant count distribution by gender across studies.



(b) Average, minimum, and maximum participant counts by gender across studies.

Figure 6.9: Study participant gender distribution visualized through two complementary charts. (a) A scatter plot showing individual participant counts by gender across five studies, highlighting variability and outliers in the data. (b) A bar chart summarizing the average, minimum, and maximum participant counts by gender for each study, providing an overview of trends and range of representation.

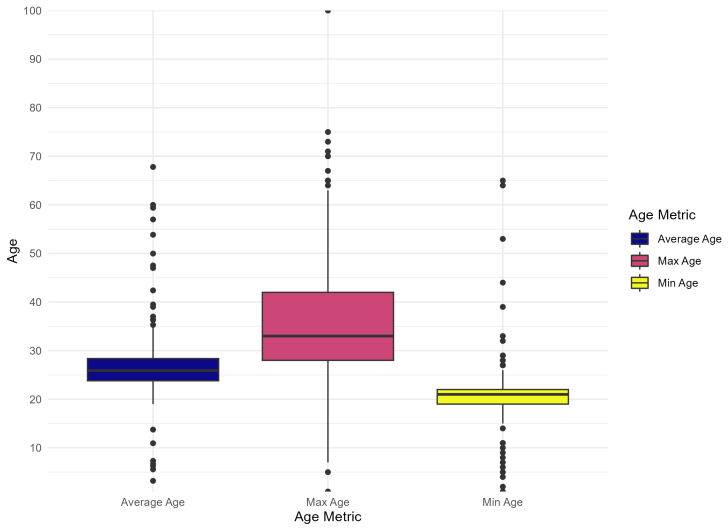


Figure 6.10: Boxplot showing the distribution of participant ages across all studies. The chart presents three age metrics: average age, maximum age, and minimum age.

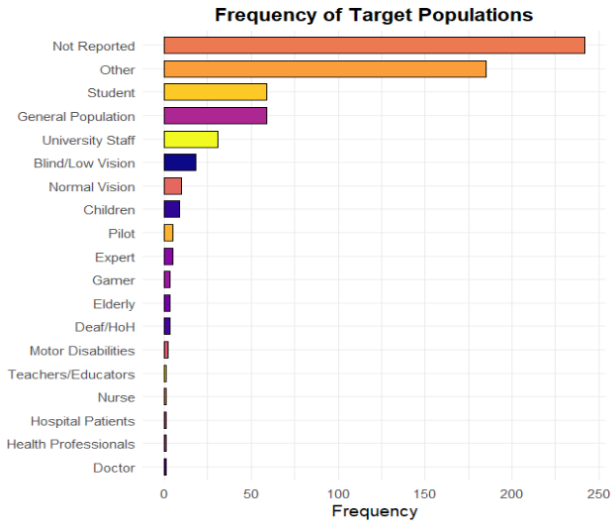


Figure 6.11: Frequency and distribution of target populations. The bar chart on the left shows that participant demographics were often not reported, with students and the general population being the most commonly specified groups.

that were reported, students and the general population were the most common participant groups, suggesting a reliance on easily accessible samples. Specialized and potentially more vulnerable populations, such as individuals with disabilities, elderly, children, and healthcare professionals, were notably underrepresented, raising concerns about the inclusivity and comprehensiveness of existing research.

Age distribution analysis Figure 6.10 supports these findings, indicating that participants' average ages clustered predominantly in the young-adult range, approximately between the mid-20s and early 30s. This age concentration aligns closely with typical student and general population profiles. The wide variability observed in maximum ages, with several outliers beyond typical young-adult ranges, highlights occasional inclusion of older adults, yet such instances remain relatively sparse. Minimum ages mostly remain tightly

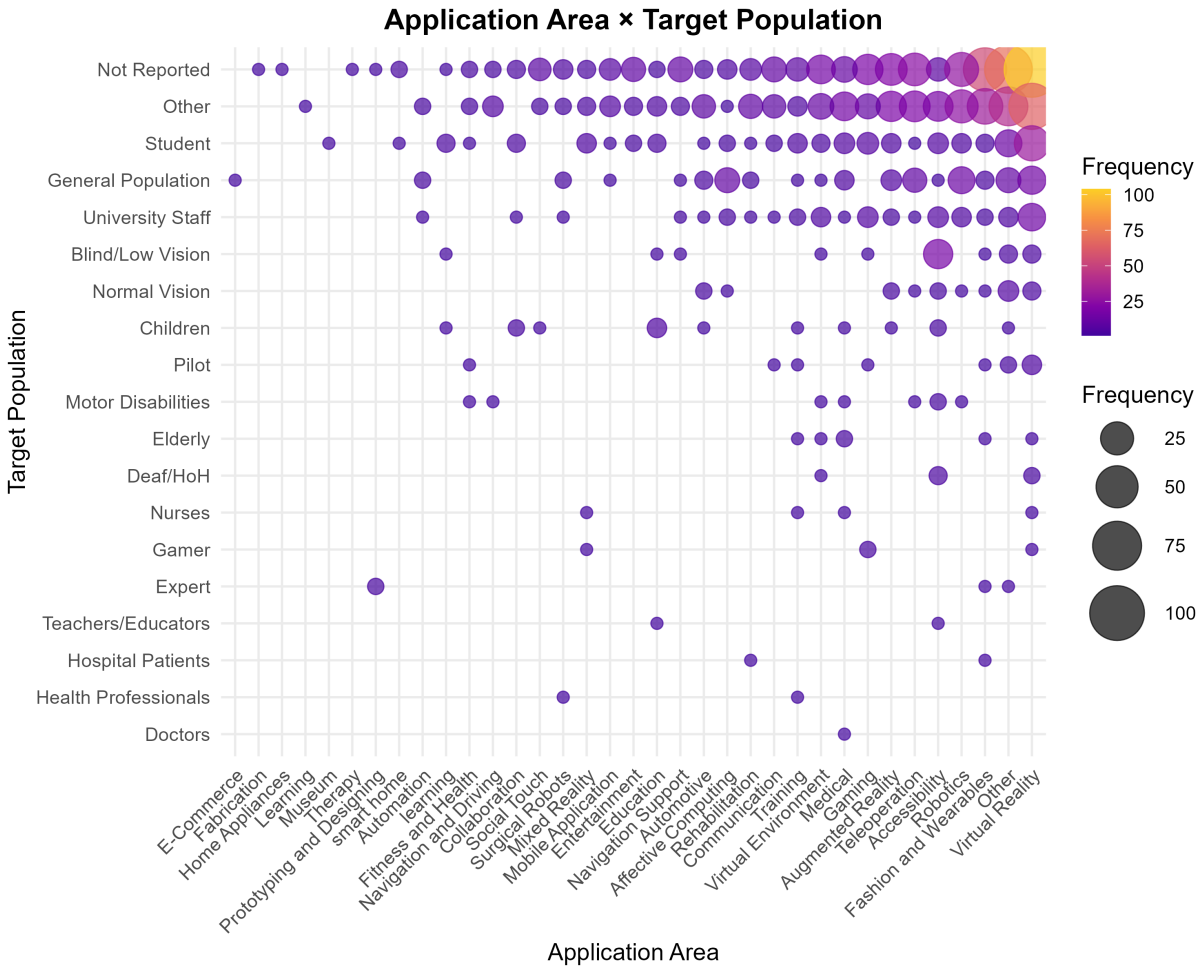


Figure 6.12: Frequency and distribution of target populations across application areas. The bubble chart on the right illustrates how these populations are distributed across different application areas, revealing a concentration in Virtual Reality, Gaming, and Assistive Technology studies.

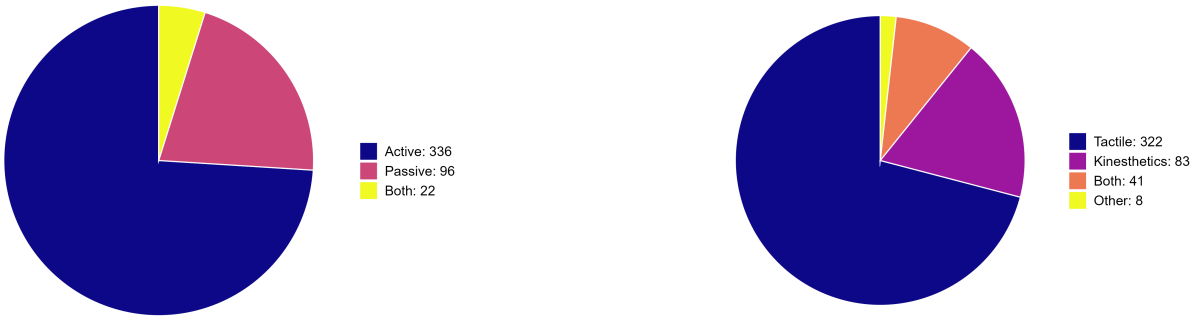
clustered around late teens to early twenties, further reinforcing the dominance of young adult participants.

Gender-related data, shown in Figure 6.9 and Figure 6.8, further emphasizes the demographic gaps in target populations. Across multiple studies Figure 6.9a, males consistently represented the majority of participants, reflecting an evident gender imbalance. The aggregated data over multiple years (2018–2023), presented in Figure 6.8a, reinforces this observation: male participants accounted for approximately 56.6% of total participants compared to 42.7% female, with an exceedingly small proportion (0.7%) reported under open-ended or non-binary gender categories. This persistent gender disparity raises important questions about the generalizability and inclusivity of findings, particularly in fields focused on user-centered design and accessibility.

Collectively, these analyses underscore a consistent reliance on convenient, easily accessible, young, and predominantly male participant groups. The significant gaps in reporting, combined with limited demographic diversity, highlight an urgent need for more comprehensive reporting practices and proactive recruitment strategies aimed at achieving greater inclusivity and representativeness in future HCI and haptic research.

6.3.3 System Specification

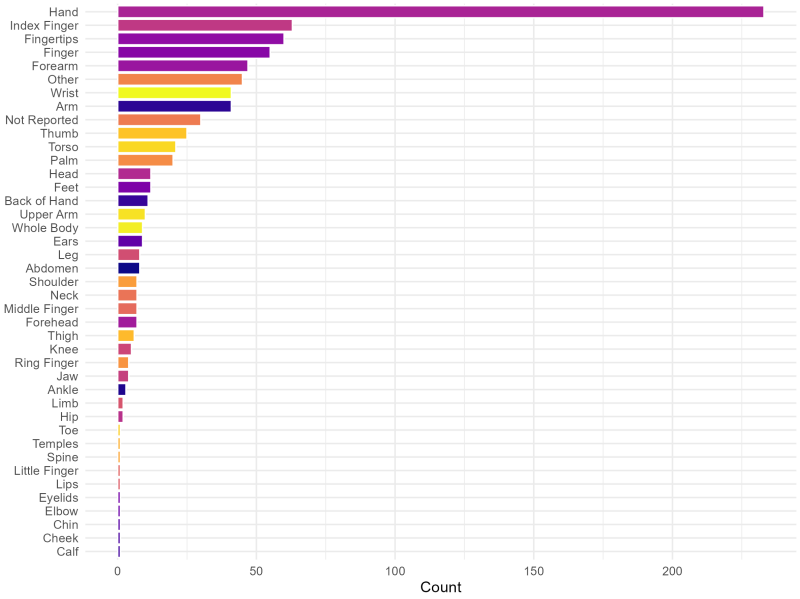
The haptic devices used across the reviewed studies highlights clear trends in the choice of interface types, targeted body locations, supporting hardware, and underlying technologies. As illustrated in Figure 6.13, the majority of interfaces (74%) were actively actuated, suggesting a strong preference for dynamic haptic experiences over passive or



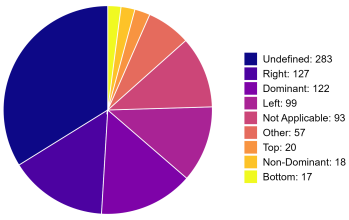
(a) Distribution of haptic interfaces

(b) Distribution of haptic feedback.

Figure 6.13: Overview of the haptic systems. (a) Interface type: the majority are actively actuated (338, 74 %), with fewer passive (96, 21 %) and hybrid active-passive devices (22, 5 %). (b) Feedback type: tactile cues dominate (322, 71 %), followed by kinesthetic force feedback (83, 18 %), systems providing both tactile and kinesthetic sensations (41, 9 %), and a small "other" group (thermal, etc.; 8, 2 %). Together, the charts reveal a clear research emphasis on actively driven, tactile-centric haptics.

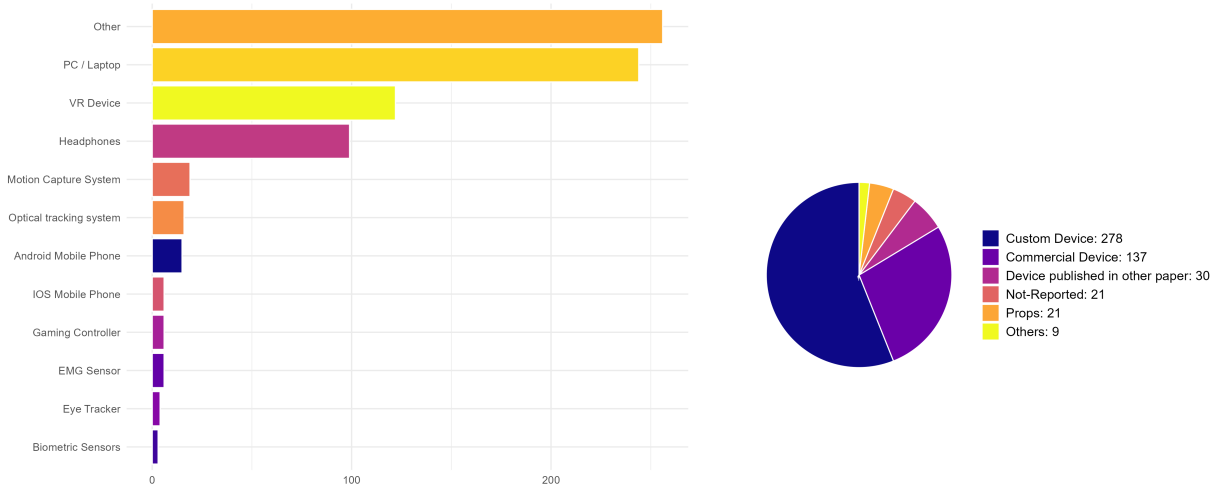


(a) Target body locations



(b) Targeted body location laterality

Figure 6.14: Targeted body included in haptics studies were reviewed. (a) Frequency of targeted body parts (46 distinct sites). Stimulation overwhelmingly focuses on the hand and its digits—Hand = 233 instances, Index finger = 63, Fingertips = 60, Finger (unspecified) = 55. Other frequently used upper-limb sites include Forearm = 47, a mixed Other category = 45, Wrist = 41, and Arm = 41. All remaining 38 locations (e.g., Thumb = 25, Torso = 21, Palm = 20, Head/Feet = 12 each) appear in fewer than 30 reports each, with many occurring only once or twice.(b) Reported laterality. One third of papers omit side information (Undefined = 283). When specified, devices favor the right or dominant side (Right = 127, Dominant = 122) over the left or non-dominant side (Left = 99, Non-Dominant = 18). Bilateral placements (Top = 20) and other/midline configurations (Other = 57), as well as bottom placements (Bottom = 17) and cases where side is irrelevant (Not Applicable = 93), are comparatively rare. Together, the plots highlight a strong research focus on hand-centric upper-limb haptics and inconsistent reporting of laterality.



(a) Supporting hardware

(b) Type of haptic device used

Figure 6.15: Haptic devices used and supporting technologies reported. (a) About one-third of studies do not specify a side (*Undefined* = 283). When given, authors favour the right (127) or the participant's dominant side (122) over the left (99) or non-dominant side (18). Mid-line or otherwise atypical configurations are comparatively rare (*Other*=57), as are explicit vertical references—*Top*=20 and *Bottom*=17. In 81 cases the notion of side is judged irrelevant (*Not Applicable*). (b) Provenance of the haptic device. Roughly two-thirds of papers present a purpose-built prototype (*Custom*, 278/496). A quarter employ off-the-shelf products (*Commercial*, 137). The remainder reuse hardware published elsewhere (30), rely on ad-hoc props (21), omit the information (21), or fall into miscellaneous Other cases (9).

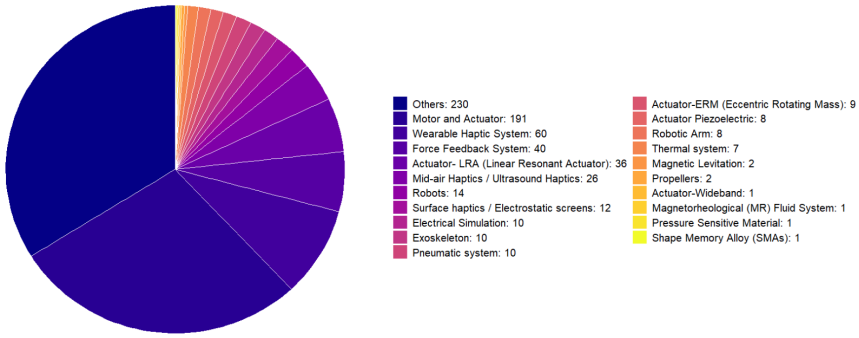


Figure 6.16: Distribution of technology used in haptic system. The most common categories are Other (230) and generic motor-based actuators (191). They are followed by wearable systems (60), force-feedback devices (40), linear-resonant actuators (36), and mid-air/ultrasound arrays (26). Robots (14), electrostatic surface haptics (12), exoskeletons, electrical or pneumatic stimulation (10 each), and solutions (9 each, e.g., ERM, piezo, therma, SMA) are reported far less often or are not clearly specified.

hybrid approaches. This aligns with the dominant use of tactile feedback (71%) compared to kinesthetic force feedback or combined modalities, reflecting researchers' emphasis on touch-based interactions.

Further examining targeted body locations Figure 6.14a, the hand and fingers emerge overwhelmingly as focal points, underscoring the field's interest in exploring precise tactile manipulation and detailed sensory feedback. Laterality Figure 6.14b reveals a notable trend of inconsistent reporting, with many studies failing to specify side preference; however, when specified, there was a clear preference for dominant or right-sided interactions, indicating possible standardization or convenience in experiment designs.

Supporting hardware usage Figure 6.15a prominently features PCs, laptops, VR devices, and headphones, which indicates a frequent pairing of haptics with immersive or multimedia environments. A substantial number of studies employed custom-built haptic devices Figure 6.15b, highlighting the experimental nature of research in this domain, with

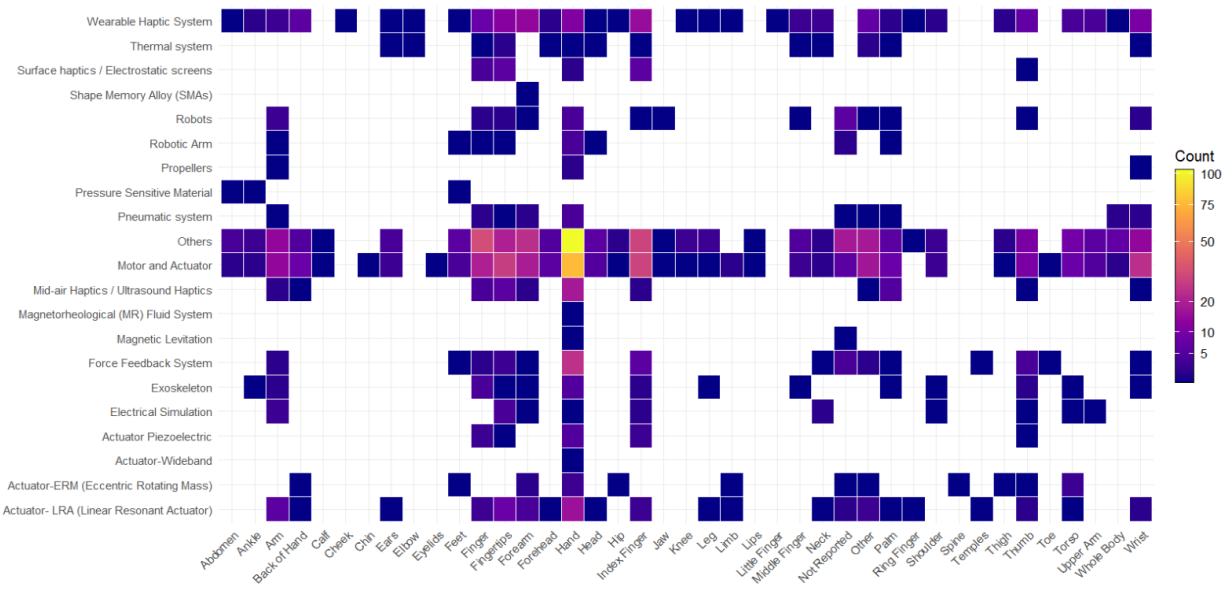


Figure 6.17: Heat-map showing how different technology used (rows) are paired with targeted body parts (columns). Conventional motors/actuators dominate and are applied almost everywhere, with the highest concentration on the hand and fingers. Wearable systems are spread across the upper limb, torso, and head, while force-feedback rigs, exoskeletons, and LRA/ERM actuators focus mainly on the hand and fingertips. Mid-air/ultrasound arrays cluster around palm-centred interaction, and robots are used chiefly for arm- and wrist-based feedback. Technologies like piezoelectric, thermal, SMA, MR fluids appear less.

approximately two-thirds utilizing custom hardware rather than commercial or off-the-shelf solutions.

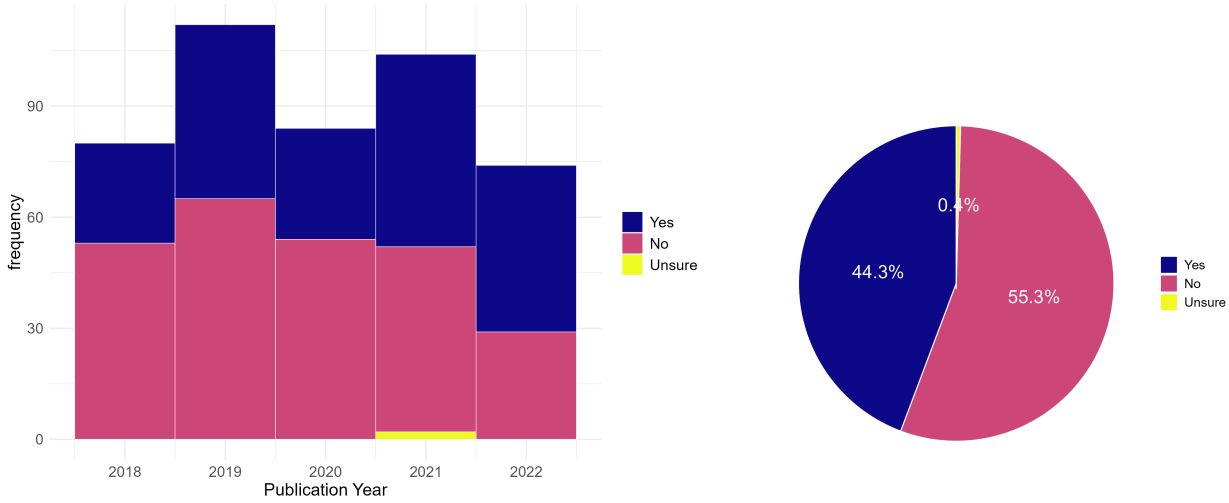
Technology distribution analysis Figure 6.16 reinforces the dominance of motor-based actuators, wearable systems, and force-feedback devices, which collectively account for a substantial portion of reported technologies. Conversely, advanced or specialized haptic technologies—such as mid-air ultrasound, thermal systems, piezoelectric actuators, and shape memory alloys—remain less common, suggesting either barriers in accessibility, complexity in implementation, or lower perceived applicability.

Device cost analysis from Tables in section 6.4 reveals a critical gap in cost-reporting practices, with most studies not disclosing device expenses. Among those that did, the vast majority fall into the Not Reported category. Only a small portion of studies reported low-cost solutions, and only a few identified their systems as very expensive, suggesting that high-cost devices are uncommon or underreported.

Finally, the heat-map visualization Figure 6.17 provides insight into how specific haptic technologies are applied to particular body regions. Conventional actuators and motors are universally applied across most body regions, particularly on hands and fingers. Wearable systems predominantly target the upper limbs and torso, while specialized systems, such as mid-air ultrasound arrays, cluster around hands, reflecting precise, localized interaction goals.Technologies such as thermal and shape-memory alloy actuators are sparsely applied. Collectively, these patterns highlight a field predominantly characterized by tactile-centric, actively actuated, hand-focused haptics using customized hardware, with significant opportunities remaining in the broader exploration and application of advanced haptic technologies.

6.3.4 Study Design and Methodology

The analysis of study design and methodology highlights several critical trends and notable gaps in reporting across reviewed studies. Ethical reporting practices Figure 6.18 reveal that nearly half (44.3%) of the reviewed papers explicitly stated obtaining ethics approval, while more than half (55.3%) indicated no ethics approval was obtained. The marginal percentage of unclear or ambiguous cases underscores the need for improved transparency



(a) Ethics approval by publication year

(b) Ethics approval distribution

Figure 6.18: Ethics-approval reporting. (a) Year-by-year breakdown (2018–2022) reveals that Yes statements and No statements occur in roughly comparable numbers each year, while very few papers are ambiguous (Unsure). (b) Looking at all the papers together, 55 % of papers report no ethics approval, 44 % affirm approval, and ¡1 % are unclear, indicating that explicit ethics disclosure is still lacking in a majority of published studies.

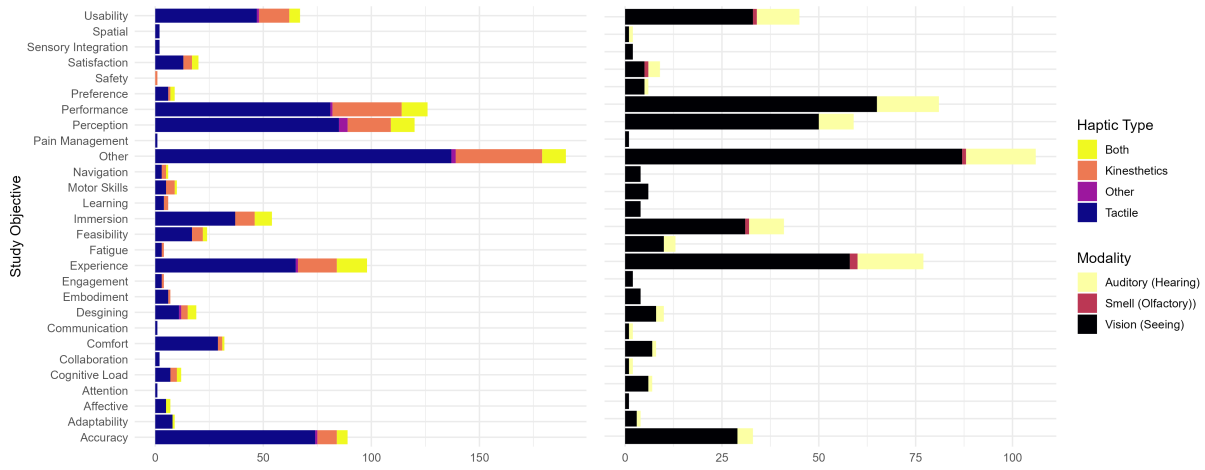


Figure 6.19: Study objectives across haptic type (left) and by modality (right). (a) Breakdown by haptic feedback type. Most objectives like performance, pain-management, usability, spatial tasks are pursued with tactile only devices. Kinesthetic only device and hybrids that deliver both tactile and kinesthetic feedback seems far less common, while Other haptic technologies appear only in a handful of studies. (b) In the same study objectives grouped by the extra sensory channel combined with haptics. Vision accompanies the vast majority of experiments, whereas auditory support is occasional and olfactory cues are rare. Across both plots the three most frequent study objectives are performance improvement, pain-management/rehabilitation, and Other, illustrating a strong reliance on tactile-visual setups and comparatively little exploration of kinesthetic or multi-sensory designs beyond vision and audio.

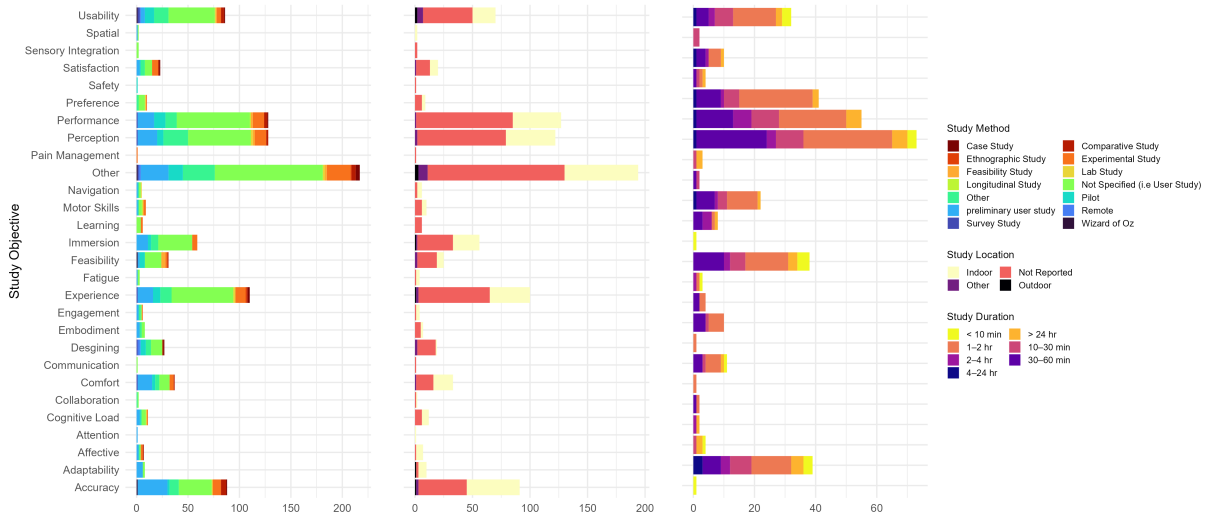


Figure 6.20: Study objectives across methods (left), location (centre panel) and by session duration (right). a) Methods (left panel). Most work that targets performance, pain management, or perception uses controlled experiments or comparative studies. Usability and feasibility are often addressed with exploratory or case-study approaches, whereas longitudinal work is scarce across all objectives. b) Locations (centre panel). Nearly every objective is investigated indoors; outdoor and Other settings are rarely used, and around one quarter of papers omit location details. c) Session durations (right panel). A clear majority of studies especially those focused on performance, pain, and usability last less than 30 minutes. Multi-hour sessions and multi-day deployments are uncommon.

and standardization in reporting ethical compliance, an essential component for research integrity and reproducibility.

Study objectives explored across haptic feedback types and modalities Figure 6.19 demonstrate a clear research focus. Performance improvement, pain management, and usability emerge as the dominant objectives, predominantly evaluated with tactile-only feedback devices. Kinesthetic and combined tactile-kinesthetic feedback devices are considerably less explored, highlighting potential gaps or challenges in implementing compre-

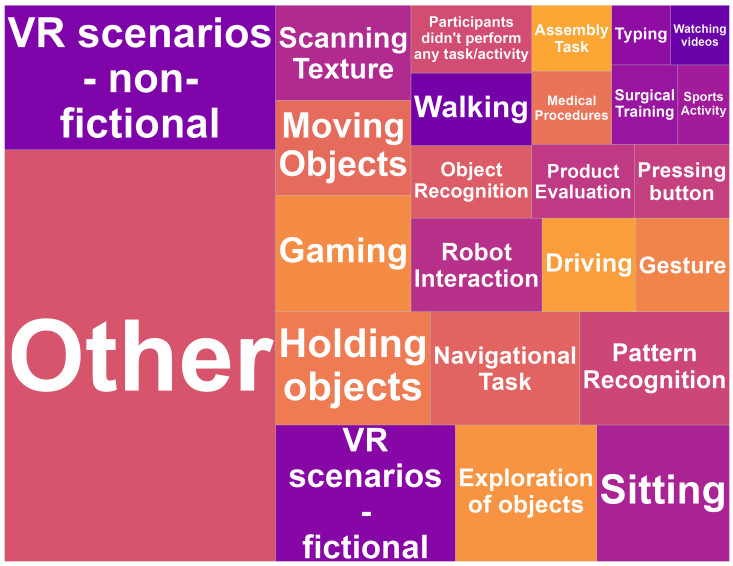


Figure 6.21: Treemap of activies done during the study. Each rectangle's area reflects how often that task was studied. The largest block, Other aggregates studies whose authors gave too little detail or whose tasks could not be mapped to any common category. VR scenarios form the next two biggest clusters: VR-non-fictional—simulations of real-world actions such as walking or running. VR-fictional—fantastical actions that are impossible in everyday life, e.g., flying, levitation, or magical powers. Additional but less-frequent tasks include manipulating or holding objects, moving objects, gaming, robot interaction, product evaluation, driving, and fine-motor activities like typing or pressing buttons.

hensive multi-sensory haptic solutions. Additionally, when combined with other sensory modalities, haptics overwhelmingly integrates visual cues, reflecting an established reliance on tactile-visual interactions, with comparatively limited auditory and negligible olfactory integration.

An examination of study objectives in relation to methodological approaches, study locations, and session durations Figure 6.20 further refines our understanding of research practices. Controlled experiments and comparative studies are the preferred methods for investigating performance and perception-related objectives, while exploratory and case-study methods primarily address usability and feasibility. Most studies were conducted indoors, with limited use or reporting of outdoor or alternative settings, reducing the ecological validity of the findings. Moreover, session durations typically fell under 30 minutes, particularly in performance, pain, and usability studies, reflecting a preference for brief interactions possibly due to resource constraints or participant burden considerations.

Finally, the activity analysis presented as a treemap Figure 6.21 illustrates the diversity of tasks studied. VR-related scenarios, both fictional and non-fictional, constitute significant portions of research activities, reinforcing the prominent role of immersive environments in current haptic research. Tasks such as manipulating and holding objects, locomotion, gaming, and robot interactions frequently occur, underscoring an emphasis on tangible and interactive tasks.

Category	Techniques Included	Total Variables
Performance & Task Metrics	Accuracy, Error Rate, Performance, Task Completion, Reaction Time, Recognition Accuracy, Exploration Time, Speed, Stability	9
Force-Related Measures	Force, Force Control Accuracy, Force Control Precision, Force Perception Precision, Force Perception Threshold, Force Profile Matching, Force Stability, Grasping Force, Peak Force, Tangential Force, Torque	11
Perceptual Qualities	Roughness, Slipperiness, Smoothness, Texture Discrimination / Identification, Spatial Resolution, Tactile Sensitivity, Temperature, Stiffness, Pressure, Frequency, Frequency Range Perception, Intensity, JND (Just Noticeable Difference), magnitude estimation/matching, Friction	15
Temporal and Spatial Measures	Time / Duration, Contact Duration, Distance, Angular Distance, Acceleration, Amplitude, Contact Area	7
Cognitive and Emotional Metrics	Emotion, Brain Activity, EEG, BCI (Brain-Computer Interface), Haptic Fatigue, Haptic Latency	6
Physical Interaction Metrics	Kinesthetic Feedback, Muscle Control, Body Movement	3
Not Reported	Not Applicable, Others	2

Table 6.2: Categorization of Evaluation Methods based on the dataset

6.3.5 Evaluation and Analysis

Analysis of study evaluation practices highlights significant trends in metrics and techniques used across research studies. The categorization of Evaluation metrics and method is in Table 6.2 and Table 6.3. Evaluation metrics primarily focus on Other (551 occurrences)

Category	Techniques Included	Total Variables
Subjective	10-point scale, 5-point scale, 7-point scale, 9-point scale, n-point scale, AttrakDiff, SAM, Rating Scale, System Usability Scale (SUS), Task Load Index (NASA-TLX), Subjective Feedback, User Satisfaction Questionnaire, User Experience Metrics	13
Behavioral & Performance	Completion Time, Error Rate, Error/Accuracy Measurement, Task Success Rate, Time-on-Task, System Performance Metrics, Fitts Law, Force Control Task, Texture Recognition Task, Hand Movement Trajectory, Gesture Recognition Accuracy, Retention Rate	12
Qualitative & Exploratory	Interview, Observation and Discussion, Open-ended Questions, Comparative Usability Evaluation, Cognitive Task Analysis, Qualitative Data Analysis	6
Physiological & Psychophysical	Event-Related Potentials (ERPs), Physiological Measures, Simulator Sickness Questionnaire, Simulated Realism Evaluation, Psychophysical Experiment, Social Presence Questionnaire, Virtual Embodiment Assessment	7
Unspecified	Questionnaire (Not Specified), Not Sure	2
Other	Other	1

Table 6.3: Categories of Evaluation Metrics and Methods

and Performance Task related metrics (529 occurrences), as illustrated in Figure 6.22. Temporal and spatial metrics (283 occurrences) are also notably prevalent, reflecting research priorities around timing accuracy and spatial precision. In contrast, specific metrics such as force-related (114 occurrences), perceptual qualities (98 occurrences), and particularly cognitive and emotional metrics (15 occurrences) are less frequently employed, pointing to a possible under-exploration of subjective and psychological dimensions in haptic evaluations.

Evaluation techniques demonstrate a similar concentration around a limited set of approaches. The dominant category by far is classified as Other (1114 occurrences), suggesting widespread use of custom or non-standardized evaluation methods, or potentially incomplete reporting. Behavioral and performance-oriented evaluations (442 occurrences) and subjective methods (303 occurrences) are the next most common, emphasizing the field's preference for quantitative measures of task effectiveness alongside user-reported feedback. Qualitative and exploratory methods (206 occurrences) appear moderately frequently, whereas physiological and psychophysical evaluations (72 occurrences) are relatively rare, indicating less emphasis on objective physiological measurements or deeper psychophysical insights.

Further insights provided by the treemap visualizations in Figure 6.23 reinforce these findings. Accuracy, time/duration, and error rates dominate as explicit evaluation metrics, underscoring the research community's prioritization of quantifiable, performance-centric outcomes. Evaluation methods commonly employed include 7-point rating scales, task load indices, and interviews, reflecting standardized and established instruments used widely across the field. However, the prevalence of a large Other category in both evaluation metrics and methods points to significant variability and a lack of standardization, which may affect comparability and reproducibility across studies.

6.4 Discussion

This scoping review synthesized evidence across a decade of empirical studies in haptic evaluation (2018-2023), revealing consistent and recurring methodological and reporting gaps.

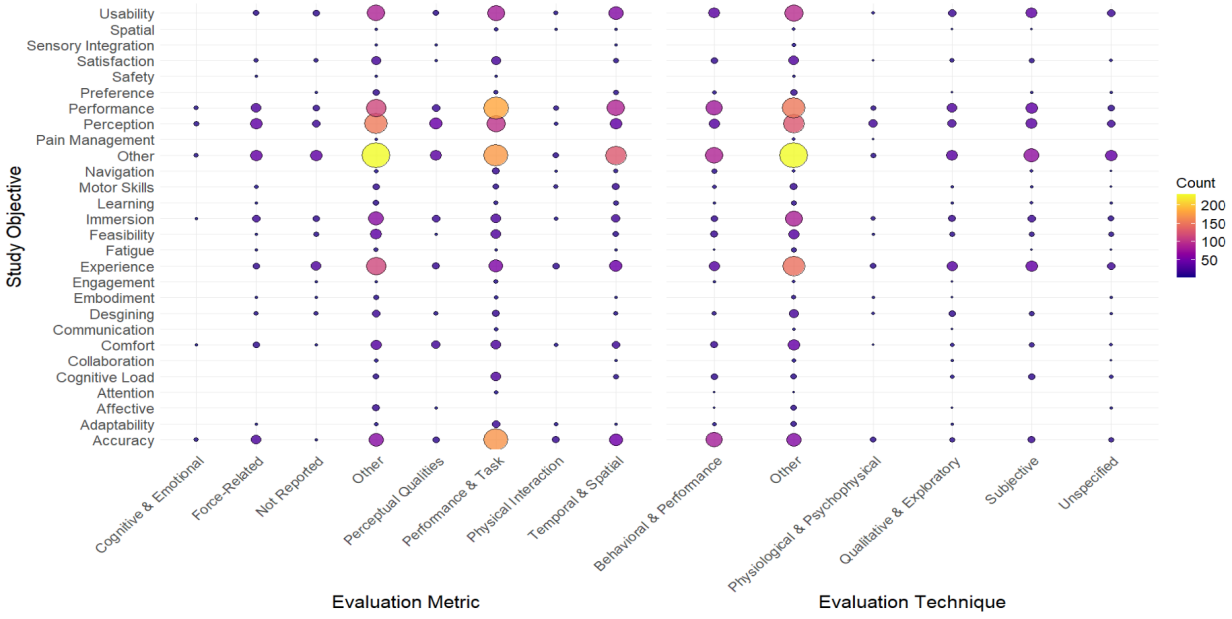
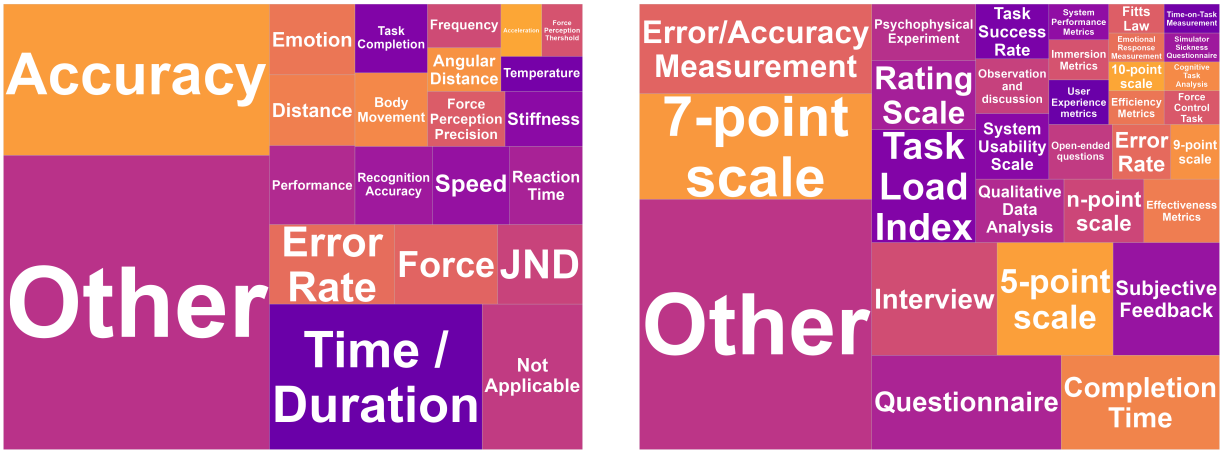


Figure 6.22: Relationship between study objectives, evaluation metrics and evaluation technique. For Evaluation Metric: Performance-and-task metrics dominate, covering most goals (Other, performance, perception and accuracy). Most of the study objectives heavily relied on Other metrics.For Evaluation Technique: Other dominate—especially for Performance, Perception, Experience, and the catch-all Other objective. Behaviour-and-performance methods come next but only in small numbers. Physiological/psychophysical sensing is almost absent. Qualitative/exploratory and subjective tools are used sparingly, mainly for Usability, Performance, Perception, and Experience.



(a) Treemap of Evalaution Metrics

(b) Treemap of Evaluation Methods

Figure 6.23: Treemap overview of Evaluation metrics and Evaluation methods. (a) Evaluation metrics. Two large blocks dominate: Other category and direct Accuracy measures. Secondary yet still frequent metrics include Time/Duration, Error Rate, Force, and JND, while numerous smaller blocks (e.g., Speed, Stiffness, Temperature, Emotion) appear only occasionally. (b) Evaluation methods. Again, an Other category is largest, followed by 7-point-scale accuracy/error logging, standard rating scales (e.g., NASA-TLX, SUS), interviews, and general questionnaires. Smaller tiles correspond to single-purpose tools such as task-success rate, completion-time logging, 9-point or 5-point scales, and qualitative data analysis.

Drawing on the empirical results presented, we propose the following evidence-informed recommendations and guidelines for researchers designing and evaluating haptic interfaces and experiences.

Table 6.4: Common reporting omissions in empirical haptic studies (2018–2023) and actionable recommendations. Percentages indicate how often each item was *Not Reported or marked as Other* across the full set of 464 papers reviewed. The Source column points to summary tables showing this issue across the top 12 most common application areas (not all papers are covered in those tables).

Recommendation	**Why it matters (missing-item stats)**	**Source**
Clearly name and cite each evaluation technique (e.g: *NASA-TLX*, Fitts' Law)	331 of 504 studies (66 %; e.g., VR 104, Wearables 36, Teleoperation 30) was "Not Reported", hindering transparency and cross-study comparison.	Table D.1 — Evaluation Technique
Define all metrics used (e.g: ms, N, Likert scale)	293 of 504 studies (58 %; e.g., VR 102, Wearables 38, Robotics 27) evaluation metrics was "Not Reported", limiting reproducibility across the literature.	Table D.1 — Evaluation Metric
Choose a recognised methodology label (e.g: experimental, case study) or justify a novel one	343 of 514 studies (67 %; e.g: Wearables 46, Accessibility 33, Teleoperation 25) was "Not Reported" or "Others," obscuring study rigour.	Table D.3 — Methodology

Recommendation	**Why it matters (missing-item stats)**	**Source**
Name the target user population (e.g: ability, expertise)	194 of 504 studies (38 %; VR 80, Robotics 21, Training 7) population was "Not-Specified," hindering relevance, replication, and equity checks	Table D.2 — Target Population
Justify sample size (e.g: power analysis, prior work, practical constraints)	112 of 504 studies (22 %; VR 22, Robotics 13, Teleoperation 11) listed their sample size as "Not Reported", providing no basis for statistical confidence.	Table D.2 — Sample Size
Report participant age using mean ± SD or range	86 of 504 studies (17 %; e.g., VR 19, Robotics 15, Teleoperation 12) omitted age entirely, limiting generalisability.	Table D.2 — Age
Provide gender breakdown (e.g: male, female, non-binary, prefer-not-to-say)	107 of 504 studies (21 %; e.g., VR 20, Robotics 13, Teleoperation 11) omitted gender information, reducing demographic transparency.	Table D.2 — Gender
Specify the study design (within-, between-, or mixed-subjects)	141 of 514 studies (27 %; e.g., VR 41, Robotics 19, Accessibility 13) recorded their design as "Not Reported," making results harder to interpret	Table D.3 — Study Design

Recommendation	**Why it matters (missing-item stats)**	**Source**
Include session duration per participant	312 of 514 studies (61 %; e.g: Virtual Reality 90, Wearables 33, Teleoperation 31) failed to report how long each session lasted, making ecological validity hard to judge.	Table D.3 — Duration
State ethics approval and consent procedures	288 of 514 studies (56 %; e.g: Virtual Reality 106, Wearables 30, Robotics 26) did not report their ethics status, especially in device-centric fields	Table D.3 — Ethics
Report device cost, origin (custom/commercial), and core technology	449 of 514 studies (87 %; e.g., VR 146, Robotics 51, Teleoperation 38) gave no cost information, and 278 studies (54 %; e.g., VR 95, Wearables 34) described their technology fall under "Others," leaving the core mechanism unclear	Table D.4 — Device Cost & Origin
Indicate device placement and laterality (e.g: dominant hand, left leg)	216 of 504 studies (43 %; e.g., VR 67, Wearables 27, Robotics 23) left the body location or laterality "Not Reported," hampering reproducibility.	Table D.4 — Body Laterality

6.4.1 Measurement Practices: From Ad-Hoc Methods to Standardization

Our review catalogues numerous evaluation concepts utilized within haptics research (Table 6.3 and Table 6.2), revealing a clear pattern: a predominant reliance on subjective, Likert-type ratings, and frequent categorisation as "Not Reported" across application domains (Table D.1). Virtual Reality studies exemplify this issue, where 103 out of 157 reviewed papers primarily utilized subjective ratings, with 102 neglecting to specify explicit metrics. Similar inadequacies were regularly found in other critical areas, including teleoperation (65%), gaming (80%), wearables (64%), robotics (52%), and accessibility (58%).

Over-reliance on ad-hoc or unreported measures — While subjective Likert-based scales offer ease of use, rapid administration, and established psychometric robustness [304], relying exclusively or predominantly on these instruments potentially limits interpretation depth and generalizability. This issue is further amplified by inconsistent and incomplete reporting of utilized measurement metrics, severely obstructing scientific reproducibility, transparency, interpretability, and cross-study comparison [133, 373]. Indeed, failure to explicitly articulate evaluation measures conflicts directly with best-practice guidance asserting that chosen metrics should be clearly traceable and aligned directly to stated user-centred objectives. Specifically, ISO 9241-210 [5] emphasizes explicit metric selection as central to robust iterative design methodologies, while ISO/IEC 25010 [6] promotes empirical grounding in measurable characteristics such as reliability, usability, and performance efficiency.

Need to use standardised metrics — Alongside the predominance of subjective methods, our review identifies a notable absence of the widespread use of standardised or validated questionnaires explicitly suited to haptics contexts. Many studies instead rely on informal, ad hoc measures (Table D.1), thereby limiting measurement quality and impeding comparability across research efforts. Addressing this shortcoming, researchers should move deliberately towards routinely employing standardised and validated evaluation instruments tailored explicitly to haptics. Recommended metrics include, but are not limited to: task completion time and error rates for performance evaluation, Just-Noticeable-Difference (JND) thresholds to assess sensory perception [186], cognitive-load assessments like NASA-TLX and EEG-based indices [217, 364], and validated experiential constructs captured in emerging domain-tailored measures such as the Haptic Experience Inventory (HXI) [500].

Report all study details — Following CHI's Artifact Review & Badging guidelines [1] and the *RepliCHI* manifesto [579], researchers should release full protocols, code, and datasets in open repositories. Pairing this openness with validated metrics and clear reporting will help the haptics community resolve lingering standardization issues and build a more cumulative and rigorous evidence base.

6.4.2 Balanced Sampling: Toward More Inclusive Participant Groups

Table D.2 highlights clear shortcomings in participant sampling practices, revealing a significant imbalance and lack of diversity in participant populations across various application areas. Most notably, samples disproportionately consist of young adults (reported mean ages typically ranging from 25 to 30 years), while groups representing different ages and

diverse abilities are considerably underrepresented. For example, in Virtual Reality (VR) studies, participants were predominantly students (25 out of 157) or drawn from the general population (15 out of 157). Conversely, groups such as older adults (only 1 of 157 papers), blind or low-vision individuals (3 of 157), and users who are Deaf or Hard-of-Hearing (2 of 157), appeared minimally or not at all. Similarly, Accessibility studies—despite their explicit relevance to specific user populations—rarely included these intended end-users such as children (2 of 40), individuals with motor disabilities (2 of 40), or blind and low-vision people (1 of 40). Teleoperation research also showed a limited alignment between stated goals and actual participant samples, with merely a single paper explicitly involving participants with motor disabilities (1 of 40).

These gaps in demographic diversity are further exacerbated by incomplete reporting practices, notably concerning participants' gender identity and age details. Gender identities were frequently underreported across multiple application domains. For instance, 20 of 157 VR studies, 10 of 59 Wearables studies, 11 of 40 Teleoperation studies, and 9 of 30 Medical studies omitted gender information entirely. Likewise, age reporting showed notable deficiencies, with 19 of 157 VR studies and 12 of 40 Accessibility studies neglecting to explicitly state participant ages. These omissions severely restrict meaningful interpretation and contextualization of study findings, significantly impairing evaluation validity and generalizability [308, 434, 115].

Furthermore, most studies recruited relatively small participant groups, further limiting representativeness and robustness. Within the VR domain, 39 of 157 studies reported small participant groups ($n < 10$), with similar limited recruitment sizes evident in Accessibility (10 of 40), Wearables (18 of 59), and Medical studies (6 of 30). Studies with small sam-

ples inherently possess lower statistical power, limited external validity, and substantially reduced potential to generalize findings to true target populations [308].

Collectively, the disparity between explicitly stated research objectives—such as claims of broad accessibility or medical relevance—and actual participant recruitment practices represents a critical methodological limitation in the field. Drawing upon established best practices and relevant guidelines [308, 434], future studies should explicitly justify and thoughtfully align participant samples with clearly defined target application groups, actively recruit diverse and representative users when feasible, and rigorously report all essential demographic details, including age, gender identity, and ability status. Adopting these higher standards will strengthen the ecological validity of evaluations, facilitate more meaningful replication and comparison studies, effectively support knowledge transfer into applied settings, and align the research community with contemporary expectations of inclusive, accessible, and representative user-centered design practices.

6.4.3 Contextual Validity: Improving Ecological Validity

Table D.3 identifies gaps in explicit context reporting, with a predominance of evaluations occurring primarily in controlled laboratory environments. Across multiple application areas, lab-based studies represented the overwhelming majority, with minimal exploration of ecologically-valid settings or real-world deployments. For instance, within the applications to Virtual Reality (VR, n=160) and Wearables (n=59), laboratory methodologies dominated the evaluations (VR: controlled experimental context in 15 studies; Wearables: lab context explicitly in 9 studies). Strikingly, less than 3% of reviewed papers explicitly

reported employing evaluations in field, remote, or ecologically valid conditions. Teleoperation (n=40), Medical (n=30), Accessibility (n=40), and Robotics (n=53) application areas similarly relied extensively on controlled experiments and laboratory conditions, with minimal reported uptake of evaluations conducted in remote, real-world environments (Remote evaluations were rare, e.g., only 1 of 59 Wearables studies and 1 of 40 Accessibility studies).

Beyond methodological context, clear and explicit reporting on study duration and user interactions was frequently inadequate, presenting considerable challenges to the interpretability and transferability of findings. Several Virtual Reality studies did not clearly report study duration (9 of 160) or participant activities (with multiple studies reporting restricted interaction types such as sitting (12), VR Fictional (30), and non-fictional tasks (62)). Such incomplete details were mirrored in studies on Robotics, with 19 of 53 papers unclear on study duration or design. Similarly, Teleoperation studies frequently omitted details about duration (13 of 40) or participant tasks (gaming and exploration tasks were minimal, 1 and 2 respectively), influencing the clarity and relevance of presented insights.

The repeated preference for controlled lab environments and consistently limited transparency in contextual and methodological documentation ultimately constrains the external validity and practical applicability of haptic evaluations [115, 292]. To enhance ecological validity, researchers are encouraged to explicitly declare detailed aspects of their study context, including the specific physical environments, technical setups (such as desktop, mobile, or VR equipment), duration clearly, and task constraints across studies [5, 434, 308]. Furthermore, studies should actively explore and report more ecologically-valid contexts, such as in-the-wild and long-term deployments, thus producing insights better aligned with real-world usage conditions and, consequently, facilitating significantly richer practical im-

plications.

6.4.4 Transparent Documentation: To Improve Device Reproducibility

Our review exposes pervasive gaps in the documentation of haptic devices. Across application areas, researchers overwhelmingly relied on *custom* hardware— *Virtual Reality* (VR) employed 90 custom versus 55 commercial devices (out of 157 studies); *Wearables*, 56 vs. 20 (out of 59); and *Robotics*, 34 vs. 17 (out of 52). Yet critical information such as *production methods*, *build costs*, and step-by-step fabrication guidelines was rarely supplied. Explicit cost reporting, for example, was missing from 146/157 VR papers, 54/59 wearable studies, 51/52 robotics papers, and 26/30 medical papers, greatly limiting assessments of cost effectiveness and scalability.

Beyond cost, key technical descriptors were also inconsistently reported. Among VR studies, authors cited diverse actuation classes—e.g., Motors & Actuators (56 papers), Wearable-style tactors (22), and Force-feedback rigs (12)—but seldom provided uniform details on components, control electronics, or performance limits. *Body laterality* was omitted in nearly half of wearable-device papers (27/59) and in 67/157 VR studies, impeding accurate interpretation of user-interaction data. Such fragmentation aligns with *Haptipedia*'s observation that device descriptions in the literature form "a dizzying array. . . with no consistent vocabulary," thwarting systematic comparison and replication efforts [494].

Fortunately, recent open-hardware exemplars illustrate better practice. Projects like *Hapkit*—a low-cost kinesthetic paddle that publishes full CAD files, firmware, and perfor-

mance characterisation [407], and wearable toolkits such as *Snaptics* [627] and *TactorBots* [620] demonstrate how detailed parts lists, 3-D designs, and controller code can radically lower replication barriers. At the policy level, the CHI Artifact Review & Badging guidelines [580] and the *RepliCHI* manifesto [579] urge authors to share "the materials, data, and code necessary to rerun the study," positioning transparency as a pre-condition for scientific progress. Embracing these norms—detailing hardware origin, actuation principles, platform dependencies, build costs, and body placement, and releasing associated CAD/PCB/firmware assets under permissive licences—will transform bespoke prototypes into reproducible and extensible building blocks, advancing haptics research as a cumulative and trustworthy discipline.

6.4.5 Ethical Transparency: Limited Ethics Reporting and the Need for Standardized Transparency

Ethical compliance and transparency constitute fundamental requirements for rigorous empirical research involving human subjects. Our review, however, reveals significant inadequacies in ethics reporting across all major application areas within haptics research. Studies commonly overlooked explicitly reporting ethical approvals or justified ethical exemptions. For example, within the Virtual Reality domain, merely 53 out of 160 studies (33%) explicitly documented ethics approval. This trend similarly appeared in Wearables (30 out of 59; 51%), Robotics (28 out of 53; 53%), Accessibility (19 out of 40; 48%), Teleoperation (22 out of 40; 55%), Medical (18 out of 30; 60%), Gaming (8 out of 25; 32%), Virtual Environment (6 out of 26; 23%), and Augmented Reality (11 out of 27; 41%).

Notably, ethics reporting was particularly sparse within contexts examining user performance and perception, such as studies on gaming or virtual environments—areas where human–system interaction intensity typically demands clear ethical oversight and transparent documentation. Failure to explicitly report on ethical approvals or exemptions poses critical barriers to accountability, participant protection, and overall methodological transparency, impeding the cumulative rigor and trustworthiness of empirical findings [115, 243].

Given these concerning findings, establishing clear ethical reporting practices must become a standardized expectation across the haptics research community. Existing guidelines, including ISO standards, publication guidelines, and best practices from related community standards, explicitly emphasize the importance of ethical transparency in human-subject research [382]. Such guidelines recommend clearly indicating ethics committee reviews, approvals, exemptions, or explicit justifications regarding the ethical appropriateness of procedures employed. Adherence to these standards ensures participants' safety, respect, confidentiality, and informed consent, ultimately reinforcing the integrity and accountability of research practices and facilitating clearer assessments of methodological rigor and validity of presented results [308]. Moving forward, transparent ethical reporting should thus be systematically reinforced, clearly documented, and consistently implemented in published haptics studies to align research practices with rigorous and responsible standards.

6.5 Conclusion

This scoping review comprehensively analyzed empirical haptic evaluation studies published between 2018 and 2023, revealing significant methodological and reporting gaps prevalent in current research practices. Our analysis identified recurring issues such as inconsistent reporting of metrics, inadequate representation of diverse participant populations, limited ecological validity, insufficient transparency in device documentation, and widespread ethical reporting deficiencies. In response, we presented evidence-informed guidelines to standardize measurement practices, encourage inclusive participant recruitment, enhance ecological validity, improve device documentation transparency, and enforce rigorous ethical reporting.

Adopting these guidelines will support the haptics research community in achieving greater reproducibility, inclusivity, and impact. Of particular concern was the frequent omission of critical demographic details such as gender identity and age, which significantly restricts the generalizability and applicability of findings across diverse user populations. Addressing these reporting gaps will be essential for ensuring that haptic technologies serve a broader and more inclusive audience.

6.6 Limitations

This review is subject to several limitations. Firstly, our dataset was limited to papers published between 2018 and 2023, potentially excluding relevant earlier research that might have influenced current practices. Additionally, although extensive, our dataset primarily

covers peer-reviewed articles from selected databases (ACM Digital Library and IEEE Xplore), possibly overlooking contributions from other sources or less prominent venues. Finally, despite careful screening and coding protocols, potential biases or omissions during data extraction cannot be entirely ruled out due to the substantial volume of reviewed literature.

6.7 Future Work

Given the comprehensive dataset and diverse visualizations produced in this review, we plan to develop interactive online tools and platforms to empower researchers to create custom visual analyses based on specific evaluation criteria, metrics, or demographic variables. Such tools would provide deeper, user-specific insights into evaluation practices, enabling more targeted and informed research.

Future research should also conduct systematic reviews focused explicitly on specific application areas, study objectives, or distinct haptic interfaces. Moreover, extending the time frame of this scoping review through longitudinal analyses could provide valuable insights into evolving evaluation trends and the long-term impact of implementing standardized guidelines. Investigating how these guidelines affect the development and user experience of haptic technologies in real-world contexts will further strengthen the field, ultimately supporting more robust and user-centered research paradigms.

Chapter 7

3C's Guideline for Haptic Systems

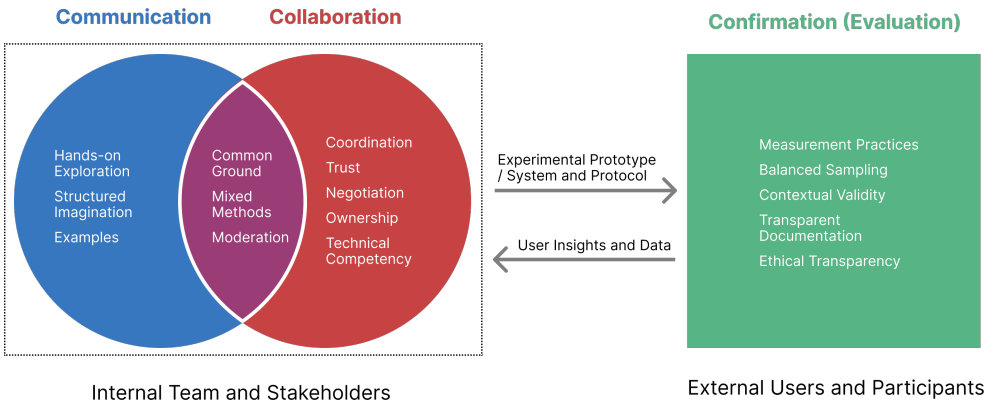


Figure 7.1: Communication and collaboration carried out between the internal team and stakeholders (left) lead to Confirmation / Evaluation, where the resulting prototype is tested with external users and participants (right); the findings then feed back into the next cycle.

Creating meaningful haptic experiences involves challenges that extend beyond technical implementation. Design for touch is personal, subjective, and often difficult for users and designers to clearly articulate. Effective haptic design demands a systematic approach

that supports communication across disciplines, smooth collaboration within diverse teams, and consistent evaluation of design decisions. Currently, the haptics research and design community lacks such a unified and structured process. As a result, efforts often become fragmented, communication becomes unclear, collaboration is ineffective, and evaluation methods remain inconsistent, significantly limiting progress in the field.

Building upon the empirical findings presented in previous chapters, this chapter introduces and elaborates each element of the proposed 3C's Guidelines. First, we discuss **Communication** (drawing on Chapter 3), highlighting how a shared vocabulary and common understanding of haptics can be established among diverse stakeholders. I then present the **Collaboration** action (drawing on Chapter 4 and 5), emphasizing the key relationships and practices needed for effective interdisciplinary teamwork. Finally, I describe **Confirmation** (drawing on Chapter 6), focusing on rigorous, transparent, and inclusive approaches to evaluating haptic design decisions and ensuring research validity. By synthesizing Communication, Collaboration, and Confirmation into an integrated framework, the 3C's Guidelines offers a structured, evidence-based approach, providing researchers and practitioners with clear directions to address the complexity of haptic design processes.

This chapter introduces the **3C's Guidelines**, a human-centered framework used to organize ideation, prototyping, and evaluation. The guideline is not a rigid set of rules but a flexible, iterative model that supports documented, ethical, and empirically grounded haptic work. It synthesizes the core findings of this thesis, arguing that successful haptic design depends on the deliberate integration of three critical, interdependent stages: **Communication**, **Collaboration**, and **Confirmation**.

7.1 The 3C's Guidelines: An Interdependent Cycle

The 3C's Guidelines are conceptualized as a continuous, iterative cycle where each stage enables the next, and the final stage informs the first. It is a dynamic process of inquiry, creation, and validation.

The relationship between the three Cs is symbiotic:

- **Communication enables Collaboration:** Effective communication, grounded in shared, hands-on experience, is the prerequisite for meaningful collaboration. When team members (hapticians, designers, domain experts, and end-users) share a common sensory vocabulary and an intuitive understanding of the technology's potential, they can contribute more effectively. Without this foundation, collaboration is often hindered by abstract discussions, technical jargon, and a fundamental disconnect between vision and reality.

- **Collaboration produces testable artifacts for Confirmation:** The goal of collaboration is to translate shared ideas into tangible prototypes. These artifacts—whether low-fidelity mockups or fully functional systems—are the concrete outputs that can be subjected to systematic evaluation. The collaborative process, guided by trust, clear roles, and shared ownership, ensures that the resulting prototype accurately embodies the collective design intent, making the subsequent evaluation interpretable.

- **Confirmation informs the next cycle of Communication:** The confirmation stage closes the loop. The data gathered—whether quantitative performance metrics or qualitative user feedback—provides new, concrete evidence. This evidence is no

longer abstract; it is a direct response to a tangible artifact. This feedback becomes the primary input for the next round of communication, allowing the team to refine their understanding, identify gaps, and set new goals. A evaluation is not an endpoint but an informative signal for a more targeted design conversation.

7.2 Communication: Bridging the Experiential Gap

Principle: The foundational stage of haptic design must be dedicated to establishing a shared, embodied understanding of touch among all stakeholders. This involves moving beyond verbal descriptions to create direct, hands-on sensory experiences.

Rationale and Evidence: The sense of touch is difficult to describe with words alone. To resolve this, the FPI study in Chapter 3 shows that non-haptician stakeholders often do not know what can be done with haptics until they can physically feel it. Verbal explanations of "vibrotactile feedback" or "force feedback" are often inadequate. This gap is best bridged through direct, physical interaction, which builds a collective sensory literacy that becomes the bedrock for subsequent design activities.

Actionable Strategies:

- **Hands-on Exploration and Examples:** Begin a haptic project in early phases with interactive sessions. Use a variety of devices to allow stakeholders to feel the technology for themselves. This is not a "demo" but a foundational learning activity.

Offer both polished, high-fidelity examples (the "Feel" step) to showcase the potential of a finished product, and modular, low-fidelity toolkits (the "Play" step) to encourage experimentation and build intuition about different modalities (vibration, heat, texture, etc.).

- **Structured Imagination:** Once a shared sensory literacy is established, use structured tools like the "Imagine" worksheets to guide stakeholders in translating their new embodied knowledge into concrete design requirements. This bridges the gap between feeling and articulating.

- **Mixed Methods for Communication:** Facilitate communication through multiple modalities. Encourage participants to use writing and verbal discussion to convey the nuanced characteristics of desired haptic sensations. Supplement with sketches, timelines, and parameter sheets where useful.

- **Multimodality and Moderation:** At the same time, remain mindful of potential sensory overload or misinterpretation, and guide users to consider the appropriate intensity, duration, and context of each haptic cue so that the final experience enhances rather than distracts or distresses users.

7.3 Collaboration: Building the Relational Infrastructure

Principle: The creative process of haptic design requires a deliberately constructed relational infrastructure that supports effective, respectful, and productive teamwork among individuals with diverse expertise and backgrounds.

Rationale and Evidence: Haptic design is inherently interdisciplinary. As the development of the Sankofa interface in Chapter 4 illustrated, a successful outcome depends on harmonizing contributions from people with diverse backgrounds - engineers, designers, community storytellers, and subject-matter experts. This requires more than just regular meetings; it demands a structured approach to managing roles, building trust, aligning motivations, and negotiating conflicts. Without this infrastructure, projects can be derailed by miscommunication, power imbalances, and conflicting priorities. Within the 3C's framework, these practices function as Collaboration scaffolds that generate artifacts ready for subsequent evaluation (Confirmation).

Actionable Strategies:

- **Coordination:** Establish clear roles and responsibilities early in the process to ensure efficient team coordination and prevent ambiguity.
- **Trust:** Build interpersonal and disciplinary trust by grounding the design process in

tangible, relationship-oriented co-design activities, particularly in real-world contexts that are meaningful to the project.

- **Common Ground:** Proactively establish a common ground by developing a shared, accessible vocabulary that bridges disciplinary divides and ensures all collaborators can contribute meaningfully.

- **Technical Competency:** Enhance the team's collective technical competency by facilitating bidirectional learning, where hapticians demonstrate technical concepts and domain experts share contextual knowledge.

- **Motivation:** Maintain motivation by explicitly connecting technical milestones and design iterations to the project's core mission and shared ethical commitments, ensuring all collaborators remain aligned on shared goals.

- **Negotiation:** Institute structured negotiation processes, such as formal design reviews and written rationales, to transparently resolve interdisciplinary tensions and make collective, traceable decisions.

- **Ownership:** Foster collective ownership by ensuring the final artifact physically embodies the contributions of each discipline, thereby solidifying a sense of shared accountability for the outcome.

7.4 Confirmation: Closing the Loop with Rigorous Evaluation

Principle: To advance the field and create effective haptic systems, design choices must be validated through transparent, and ethically sound evaluation. In 3C's, Confirmation emphasizes consistent study design and reporting so results are interpretable and comparable.

Rationale and Evidence: The systematic review in Chapter 5 revealed significant and pervasive shortcomings in how haptic systems are evaluated. The field is characterized by a reliance on ad-hoc or unreported metrics, a lack of demographic diversity in participant samples, a preference for controlled lab studies with limited real-world validity, and poor documentation of both methods and device specifications. These gaps not only hinder scientific reproducibility but also limit our ability to understand the true impact and value of the technologies we create. confirmation is essential to move from "it works" to establishing effectiveness and usability for target users.

Actionable Strategies:

- **Measurement Practices:** Employ standardized and validated metrics (e.g., NASA-TLX, SUS, psychophysical methods like JND) where possible, to complement and ground custom questionnaires.

- **Balanced Sampling:** Recruit participants who reflect the actual target population. Go beyond convenience samples to include varied ages, abilities, and backgrounds.
- **Contextual Validity:** While lab studies are valuable for control, supplement them with evaluations in ecologically valid, "in-the-wild" settings that reflect real-world use cases.
- **Transparent Documentation:** Fully document all aspects of the study and the technology. This includes detailed methods, participant demographics, and complete technical specifications of the haptic device (including cost and build instructions where feasible).
- **Ethical Transparency:** Report institutional review board (IRB) or ethics committee approval, and detail the informed consent procedures undertaken to protect participants.

7.4.1 Maturity Mapping via Technology Readiness Levels (TRL)

We position the 3C's guideline with a method-maturity mapping using Technology Readiness Levels (TRL), a 1–9 scale widely used to evidence technology maturity and integration risk [358]. Because 3C's is a socio-technical method, we follow recent adaptations that interpret TRL constructs (evidence and environment) for non-hardware interventions, focusing on demonstrated outcomes in relevant settings and independent replication [468].

Implications and next steps. To move from lab demos (TRL 4) to real-world use (TRL 5–6), we will have independent teams in different fields repeat the work with the

same materials, run planned (ideally preregistered) studies that compare 3C's with common practice, and release reusable worksheets, checklists, and data formats while tracking who uses them and what results they get.

7.5 Conclusion

The 3C's Guidelines integrate Communication, Collaboration, and Confirmation, providing a structured yet flexible process for haptic development, particularly for organizing ideation, prototyping, and evaluation. It contends that the creation of haptic technology is not simply an engineering challenge but a human-centered one, demanding continuous investment in building shared understanding, fostering productive teamwork, and committing to systematic validation consistent with iterative HCI practices.

By moving beyond fragmented, technology-first approaches, this guideline offers researchers and practitioners a way to produce systems that are usable, interpretable, and empirically grounded. By embracing Communication, Collaboration, and Confirmation in the development process, we can build a more coherent and reproducible foundation for the science and design of touch.

7.5.1 Future Work

The findings and limitations of this thesis point to several promising avenues for future research. Consistent with the readiness discussion in Section 7.4.1, we emphasize evidence accumulation, replication, and adoption tracking rather than a single maturity verdict.

First, the 3C's Guidelines should be further evaluated and refined across a wider range of contexts. Future work could involve applying the guideline to different application domains in HCI that involve novel hardware and software integration, such as virtual/augmented reality, medical simulation, and teleoperation, and with teams of varying sizes and compositions. Furthermore, the 3C's Guidelines require more extensive study to explore its nuances. Research is needed to investigate the different roles within haptics teams, how evaluation techniques should differ based on study objectives and technologies, and what specific tools and methods can best improve Communication, Collaboration, and Confirmation. Finally, developing a digital platform or toolkit to implement the 3C's process could support dissemination and lower barriers to adoption.

Second, research is needed to expand and diversify the tools available for the Communication stage. This could include developing more modular and accessible haptic toolkits, creating standardized vocabularies for describing tactile sensations, and exploring the use of AI-driven tools to help translate user descriptions into haptic parameters.

Third, the action of Collaboration identified in the Sankofa project could be developed into more formal models for managing interdisciplinary haptic teams. Future studies could investigate how different collaborative structures, communication protocols, and ethical frameworks impact design outcomes and team dynamics. There is a particular need for research on effective collaboration in remote and distributed teams, a scenario that has become increasingly common.

Fourth, the haptics community must collectively address the gaps identified in Confirmation. This includes the development and validation of standardized, open-source evaluation instruments tailored to haptic experience. Longitudinal, "in-the-wild" studies are also

critically needed to understand how haptic systems are used and experienced over time in real-world settings. Establishing a community-driven repository for sharing haptic device designs, evaluation data, and analysis code would be a significant step toward building a more cumulative and reproducible science of touch.

Finally, instead of giving a single TRL score, I present a simple maturity map for the 3C's (Section 7.4.1). In the future, to make 3C's ready for everyday projects, we need to: (1) have independent teams try it in their own work; (2) run pre-planned studies that compare 3C's with current practice; (3) publish ready-to-use materials (worksheets, checklists, data formats) and track who uses them and with what results; and (4) run the same study at multiple sites using the same report template so results are easy to compare.

In conclusion, the future of haptics will be defined not only by technological innovation but by the maturity of our design processes. By embracing a more structured, human-centered, and ethically-aware approach, we can move beyond creating novel devices to designing useful and empirically supported haptic experiences.

Table 7.1: Component-level TRL mapping for 3C's (evidence drawn from Ch. 3–6); TRL interpreted per Mankins et al. [358] as lab → relevant environment → operational demonstration.

Component	**Mapped TRL**	**Current evidence and advancement criteria**
Communication (FPI; tools)	**4**	Demonstrated with participants to build shared sensory literacy and elicit requirements using hands-on exemplars and worksheets (FPI: Feel–Play–Imagine) in controlled settings (Ch. 3). *Toward TRL 5–6:* independent replications in relevant project environments with pre-registered measures (e.g., requirements completeness, reviewer's agreement).
Collaboration (co-design practices)	**4**	Shown in a longitudinal co-design (Sankofa) and a time-boxed workshop, using boundary objects and role structuring to coordinate work (Ch. 5). *Toward TRL 5–6:* multi-team deployments across domains; report coordination/integration outcomes.
Confirmation (reporting checklists & study guidance)	**2–3**	Consolidated needs via a scoping review and an initial structured case; field-adopted instruments and external replications remain pending (Ch. 6). *Toward TRL 4–5:* establish reliability for reporting fields; comparative studies of measure bundles.

Chapter 8

Conclusion

This thesis addressed a fundamental challenge in the field of haptics: the absence of standardized guidelines or processes for its design and evaluation. Through a synthesis of insights from empirical studies, collaborative co-design projects, and scoping reviews, this work articulated and examined the "3C's" guideline —a flexible, iterative model used to structure the early phases of ideation, prototyping, and evaluation, centered on Communication, Collaboration, and Confirmation. The central argument of this dissertation is that usable and well-specified haptic systems are best produced through human-centred, participatory, and agile development practices, processes that let haptics teams iteratively integrate hardware, software, and user-experience validation from concept to deployment.

The research presented in this thesis makes several key contributions to the field. First, it identified and addressed the communication gap in haptic design through the Feel-Play-Imagine (FPI) process. This structured method for Communication demonstrated that direct, hands-on engagement with a diverse range of haptic modalities is essential

for building a shared sensory literacy among stakeholders. By moving beyond abstract verbal descriptions, the FPI process empowers both novice and expert practitioners to translate embodied understanding into concrete design requirements, bridging the gap between technical possibility and experiential goals.

Second, through the multi-year co-design of the Sankofa interface, this thesis provided a deep, longitudinal case study of interdisciplinary Collaboration in a sensitive, community-driven project. This work highlighted the critical importance of building a relationship that fosters trust, synchronizes diverse work rhythms, and establishes shared ethical commitments. The Sankofa project illustrated how symbolic artifacts can serve as powerful boundary objects, and how situating co-design in authentic, meaningful contexts can enhance collaborative imagination. It also underscored the necessity of acknowledging and managing the emotional labor inherent in justice-oriented design work.

Third, the scoping review of 464 empirical studies offered a comprehensive map of Confirmation practices in haptics research, revealing significant and persistent gaps in evaluation methodology. This review exposed a widespread reliance on ad-hoc metrics, a lack of demographic diversity in participant samples, and a need for greater transparency in documenting both methods and device specifications. In response, this thesis provides a set of evidence-based recommendations to guide researchers toward more rigorous, reproducible, and ethically sound evaluation practices.

Ultimately, the 3C's guideline provides a cohesive framework that integrates these three pillars into an interdependent cycle. Effective Communication enables meaningful Collaboration, which in turn produces testable artifacts for rigorous Confirmation. The findings from the Confirmation stage then feed back to inform the next cycle of Communication,

creating a continuous loop of inquiry, creation, and validation.

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Appendix A

Haptic Mini-Tour and Tickle Trunk

A.1 Haptic Mini-Tour

Haptic Mini-Tour included the following collection of commercial haptic devices for our workshop and expert study as these devices were readily available to us in our lab:

- Haply: A haptic force-feedback device created by Haply Robotics (`https://haply.co`). This is a low-cost 2DOF force feedback device use for prototyping and haptics education. The demo consisted of a visual interface showing a 2-D maze game with force-feedback walls, dynamic 2-D shapes, and damping in a water section. The user received the force feedback through the handle, users could finish the game or just explore the interface to understand more about force-feedback devices.

- 3D Systems Touch: A mid-range, professional haptic device used in research, 3D modeling, and more (`https://www.3dsystems.com`). The device provides 3DOF force

feedback which allows users to feel virtual objects and touch sensations in a 3D environment. The demo consisted of a visual interface showing included games and activities like poking different bubbles in a 3D space where user to felt feedback like vibration, force-feedback and damping.

- Avengers Vybe Haptic Gaming Chair: A vibrotactile device that provides tactile sensation to users while playing games, movies or storybooks, etc. The demo consisted of a version involving custom firmware connected to an experienced designed to add vibrotactile feedback to Minecraft [484], such as raindrops on the back or a galloping horse under the seat of the player.

- Tanvas: A surface haptics device that processes different haptic effects textures on the screen and allows user to feel different textures when they swipe their fingers on it (`https://tanvas.co/`). The demo consisted of a visual interface showing different images the users could feel through the screen. An included demo suite with application like a shaving razor blade ad where the user feels the beard, and an archaeology app where the user uses a brush to uncover fossils underneath the sand.

A haptician provides an explanation and demonstration of each device included in the Mini-Tour, using relatable examples to help storytellers visualize how the devices can be used in various scenarios. After the demonstration, storytellers interact with demo applications to experience the haptic feedback of the devices. This process is repeated for all devices included in the Mini-Tour. Instead of using a fixed script, the examples are adapted based on the storytellers' background and experience.

A.1.1 Tickle Trunk

The Tickle Trunk is an open-source, custom-built tangible toolkit that allows users to experiment with tangible, haptic, and physical interactions using a wide range of modalities. The Tickle Trunk uses different inputs such as pressure, shake, and turn that map to output effects such as heat, vibration, and force feedback. It allows participants to use the device using a plug-and-play system to help storytellers and designers to come with ideas, rapidly explore different sensations, and prototype how haptics could be used in the stories.

The Tickle Trunk has several "widgets", each of which encapsulates a specific interaction technique or modality. The Tickle Trunk is completely hardware based; no coding is required to mix and match the widgets to try out different combinations of modalities. Widgets are divided into two groups, inputs and outputs:

- Inputs (painted white) are sensors; they modulate output sensations through different actions like proximity, force sensing, clicking, touching, lighting something, shaking, twisting and sliding.

- Outputs (painted black) are actuators; they are controlled through the input widgets to be able to feel different physical feedback like vibrations, force feedback, shape changing, temperature, wind, warmth, and textures.

A more detailed explanation of each widget is described in Table A.1.

Input Widgets	
Push button	Switch activated with a simple press. The button is similar to one used in an arcade gaming machine.
Shaker	Sensor activated by shaking the widget, similar to the shape and size of a tennis ball, it contains a spring-type vibration switch.
Slider	Switch activated by sliding the potentiometer to the right for increased intensity and left for decreased.
Candle	Sensor activated by igniting a flame close to the widget, serving as an ON/OFF switch.
Gesture box	Sensor activated by performing gestures with a magnetic bracelet above the box which contains a linear hall sensor.
Turning wheel	Activated by turning the potentiometer wheel clockwise varying the resistance, increased intensity for clockwise movement and decreased for counter clockwise.
Output Widgets	
Fan	When activated blows air to the user with a small fan.
Vibration handle	When activated it vibrates using a 12 volt double shaft DC motor.
Vibration pen	When activated it vibrates using a 3 volt single shaft DC motor.
Shape changer	When activated a pump blows up a silicone bubble that users can interact with by pressing it.
Temperature box	When activated a Peltier module changes temperature depending on the setting, it can heat up or cool down.
Lights	When activated they irradiate warmth and light through incandescent bulbs.
Motion box	When activated the movement generated acts as force feedback sensed by the users when they lay their hands on the box.

Table A.1: Shows function of different input and output widgets available in the Tickle Trunk

The Tickle Trunk uses a position-based linear control. Each input can activate up to three outputs when connected in the same coloured channel. Once connected, by activating the input the connected outputs will be activated as well. Some input widgets can also modulate the output effects. For example, a button causes an output to activate (when

pressed)/not activate (when not pressed), but the shaker, slider, and wheel can intensify the output effect by shaking in a higher frequency, moving the slider from one end to the other, or rotating the wheel in a clockwise angle. A small change in input corresponds to a small change in output and the output remains unchanged until the input is varied again. The general state of input and output widgets was considered as "always-OFF", until a trigger changes the state of input and output to "ON".

A plug and play system was designed to encourage storytellers to learn and explore haptic sensations in an easy and playful way. There are three channels (i.e., a mapping from input to outputs) ; for each channel, a single input maps to up to three outputs (all of which respond simultaneously to the input). We chose this design so that users can experiment different combinations of more than one output at the time, but limited the design to three channels and three outputs per channel to balance flexibility and simplicity. The visual and material design of the Tickle Trunk was chosen to be accessible and not intimidating by labelling each channel with different colored arrows to show which input maps to the outputs. Widgets were painted different colors (black and white) for better visual discrimination between them, with corresponding colours on the main board.

The haptic sensations chosen for the widgets, both input and output, were based on rendering tactile feedback to the user through vibration, touch, pressure, temperature, force feedback, tangibles and texture [309]. The overall design of the widgets targeted both specific objects from the stories and general shapes. This was to show flexibility, the widgets can be shaped to be any object (e.g. candle), but also keep some with an open design (e.g. sphere) so that users can imagine other uses due to its ambiguous shape.

Sketches, plans and guidelines for the design and creation of a Tickle Trunk will be

Story Description: People, Environment, Actions and Outcomes

Story Name	Journey to Annapurna
Story ID	Journey1
Who are you telling this story? (audience)	People who love trekking and travelling
Was it an individual or shared/collective experience? (Like did you experience it with others or individually)	Collective Experience - me along with my three undergraduate friends
Environment	
Where is the story taking place?	From Kathmandu to Annapurna Base camp
At what time is this story taking place? (Afternoon, Morning, Evening)	Three days journey Viewing scenery at afternoon and evening Playing card games at night
What are there in the surrounding environment? Which is important to this story?	- Swerving roads and bus ride was dangerous - Bus ride had a rumbling sensation due to engine noise and vibration - Playing with snow at the top of the base camp - Cards were played in a small room of a lodge where everyone was laughing around
Who else is there in the story and how would they influence in this story?	- Travelled with friends is different from solo - Friends are funny and cheerful which made a trip a different experience compared to traveling solo. - One of the friends was travelling fast and others were just taking time. - There was some competition while playing snowball game
How could you relate above action with haptics or sense of touch? (If it helps, please use metaphor and examples to explain your story. It doesn't have to be literal; it can be emotional as well)	- Bus: shaking, vibrating (whole body) - Walking- like a point tapping sensation (back or hand) - Standing while its snowing: cold or like snow, random taps (back or hand) - Playing with snow: When someone throws a snow at you it's like a fist bump sensation 
Please define the body part for the sensation if possible	- Meeting people: warmth, fun, joy: vibration or sensation radiating outside (back or hand)  - Cards: swipe with sound (hand)

Figure A.1: PEAO included in Worksheet consists of questions related to environment, actions and outcomes

made open-source and available to the community.

A.1.2 Worksheet and Pamphlet

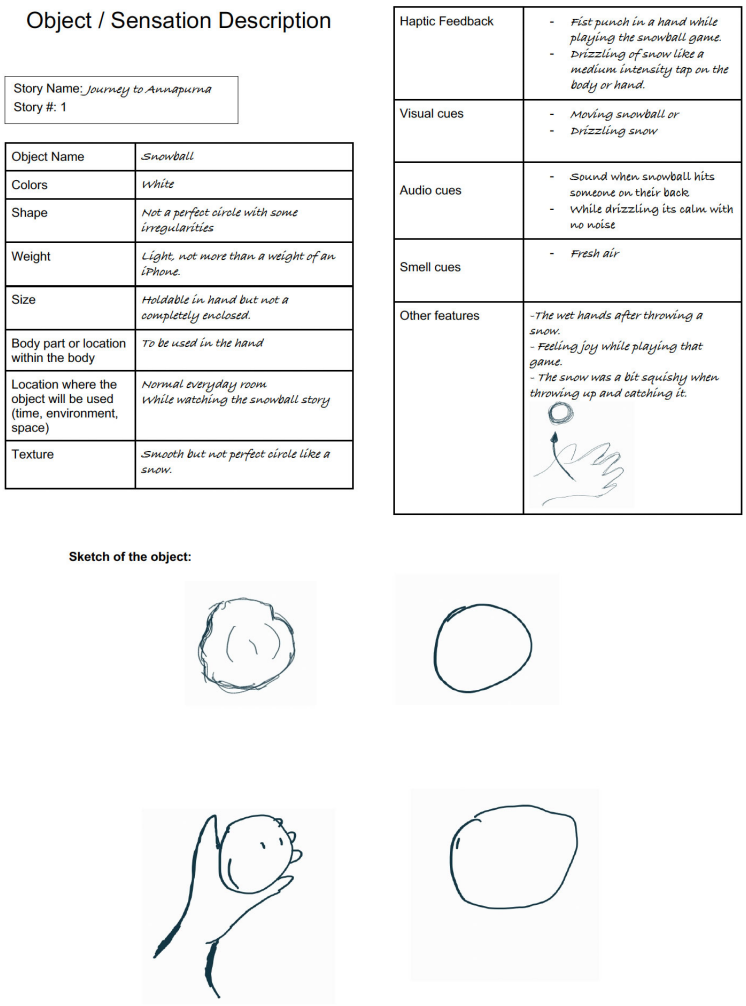


Figure A.2: Object Description sheet included in the Worksheet consists of questions related to haptic object/device storytellers wants to use to provide haptic feedback

Appendix B

FPI Study Materials and Ethics

Department of Management Sciences
200 University Ave. W, Waterloo
ON Canada, N2L 3G1

EXPERT INPUT - CONSENT FORM

Project Title: Tickle Trunk: Requirement gathering tool for haptic storytelling
Principal Investigator: Oliver Schneider, Assistant Professor, 1-519-888-4567 ext.38505
Student Investigators: Bibhushan Raj Joshi, PhD Student, Dept. of Management Sciences, b3joshi@uwaterloo.ca, Ana Lucia Diaz de Leon Derby, Master's Student, Dept. of Systems Design Engineering, aldiazdeleonderby@uwaterloo.ca
Research Assistant: Fiona Yang, Undergraduate Student, Dept. of Psychology, f239yang@uwaterloo.ca

We are inviting you to participate in our study to offer your inputs towards the requirement gathering tools used for haptic storytelling called Tickle Trunk. The purpose of this study is to evaluate usefulness, challenges, and advantage of using the Tickle Trunk to effectively gather requirements and consequently help them to build an effective haptic system. In order to be eligible for the study, you must have some experience and expertise in the field of storytelling, designing, haptics or visual art. You will not be eligible to participate if you have no knowledge in these field.

Firstly, you will be asked to fill brief questionnaires related with demographics and your familiarity with storytelling, designing and haptic feedback. In the second step, given a demo of haptic tools included in the study which consists of four commercial devices, a custom hardware tool and set of procedure that the hapticians (people who work in haptics) can follow to gather requirements. In the third step, you will be asked to add haptics in a story. For this, participants are encouraged to bring their own short story (needs to be available in audio, video, visual art, or written format, and it should fit in the time slot of five minutes). Otherwise, a short story for kids will be provided to the participants to experiment with the haptic feedback and requirement gathering process using the Tickle Trunk. At the end, the participants need to answer to questions related to the stories and the tools they decided to use in the story. In the fourth step, you will be asked to give usability feedback for each tool used during the demo and story sessions (i.e., second and third step). Finally in the last step, you will be asked to give a general feedback and potential of using the Tickle Trunk.

Devices to be used:

- Haply: The Haply is a haptic force-feedback device provided by Haply Robotics (based in Montréal). This device is used for variety of prototyping and study procedures related to force-feedback perception, control, and design. The device is a low-cost two degree of freedom-force feedback device.



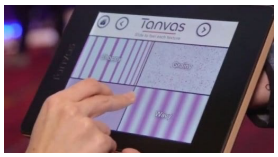
- 3D System: 3D systems is a mid-range, professional haptic device in research, 3D modeling, OEM applications, and more. The device applied three degree of freedom force feedback which allows user to feel virtual objects and touch sensation in a 3D environment.



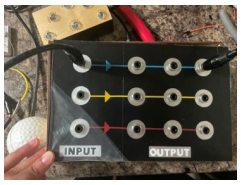
- Feel craft: Feel craft is vibrotactile device that provides tactile sensation to users while playing games, movies or storybooks, etc.



- Tanvas: Tanvas is a surface haptic device which process different haptic effects textures on the screen which the user can feel when they swipe their fingers.



- Switchboard: Switchboard is a device made by Haptic Experience Lab which helps users to experiments with different form of haptic inputs and outputs such as heat, pressure, vibration, etc.



With your permission, photos, video, and audio recordings of the design, planning and discussion session will be collected for further observation or analysis of the steps and methods used by participants to integrate haptics in their stories. You will also be asked for permission to share recordings with the research community through seminars, conferences, and journal articles. At no time will recordings be identified by name. If you agree to allow your recording to be shared publicly, you will be given the option of having identifying features blurred or obscured. You do not need to agree for your session to be recorded or shared to participate in the study. Other study data may also be shared publicly (e.g., survey results). Your name will never be associated with your individual data, and things that can identify you (e.g., identifying demographics) will be removed prior to this sharing.

You can request your data to be removed from the study till 30 days after the last study is done as the data from this study will be anonymized and shared with the research community through seminars, conferences, and journal articles. Any data collected during the study will be stored on ECResearch, a secure network file server for University of Waterloo Engineering faculty members. Only the researchers at the University of Waterloo involved in the study will have access to original data. For the pictures, the researcher will ask whether the participants are comfortable with including their faces for research papers and journals if not the participant's face will be blurred to avoid recognition.

When information is transmitted over the internet, privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). University of Waterloo researchers will not collect or use internet protocol (IP) addresses or other information which could link your participation to your computer or electronic device without first informing you.

You may refuse or skip any task or question without affecting your remuneration.

REMUNERATION: We are very grateful for your participation. In appreciation of your time, you will receive cash in the amount of $20.00. (The amount received is taxable. It is your responsibility to report this amount for income tax purposes)

TIME COMMITMENT: 90 minutes session

RISKS & BENEFITS: This study contains no risk.
There are no direct benefits to participants.

CONFIDENTIALITY: *You will not be identified by name in any study reports. Any data gathered from this experiment will be stored in a secure account accessible only to the experimenters.*

You understand that the experimenter will ANSWER ANY QUESTIONS you have about the instructions of the procedures of this study. After participating the experimenter will answer any other questions you have about this study. **Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time up until the point at which your data is anonymized (i.e., 30 days after the last study is done). You may refuse to participate or withdraw before this point without jeopardy.** Accepting the consent indicates that you have received a copy of this consent form for

your own records, and consent to participate in this study. By consenting to participate in this study, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (ORE #44482). If you have questions for the Board, contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or reb@uwaterloo.ca.

The study is funded by New Frontiers for Research Foundation (NFRF)

If you have questions about the study or related research, please contact Dr. Oliver Schneider at oliver.schneider@uwaterloo.ca.

Example Haptic Storytelling Tool Questionnaire

Start of Block: Consent

Q137 **Welcome to Haptic Storytelling User Study !!!**

Consent Form **Project Title:** Tickle Trunk: Requirement gathering tool for haptic storytelling

Principal Investigator: Oliver Schneider, Assistant Professor, 1-519-888-4567 ext.38505

Student Investigators: Bibhushan Raj Joshi, PhD Student, Dept. of Management Sciences, b3joshi@uwaterloo.ca, Ana Lucia Diaz de Leon Derby, Master's Student, Dept. of Systems Design Engineering, aldiazdeleonderby@uwaterloo.ca

Research Assistant: Fiona Yang, Undergraduate Student, Dept. of Psychology, f239yang@uwaterloo.ca

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You may refuse or skip any task or question without affecting your remuneration.

REMUNERATION: We are very grateful for your participation. In appreciation of your time, you will receive cash in the amount up to $20.00. (The amount received is taxable. It is your responsibility to report this amount for income tax purposes)
TIME COMMITMENT: 90 minutes session
RISKS & BENEFITS: This study contains no risk.
There are no direct benefits to participants.

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You understand that the experimenter will ANSWER ANY QUESTIONS you have about the instructions of the procedures of this study. After participating the experimenter will answer any other questions you have about this study. **Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time up until the point at which your data is anonymized (i.e., 30 days after the last study is done). You may refuse to participate or withdraw before this point without jeopardy**. Accepting the consent indicates that you have received a copy of this consent form for your own records, and consent to participate in this study. By consenting to participate in this study, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

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The study is funded by New Frontiers for Research Foundation (NFRF) If you have questions about the study or related research, please contact Dr. Oliver Schneider at oliver.schneider@uwaterloo.ca.

- ○ I agree to participate in the study (1)
- ○ I do not agree to participate in this study (2)

Skip To: End of Survey If Welcome to Haptic Storytelling User Study !!! Consent Form Project Title: Tickle Trunk: Requireme... = I do not agree to participate in this study

End of Block: Consent

Start of Block: Video and Data Consent Form

Q148 Media and Data Collected from the study

You will not be identified by name in any study reports. Any data gathered from this experiment will be stored in a secure account accessible only to the experimenters.

Q142 I agree to the use of anonymous quotations in any thesis or publication that comes from this research.

- ○ Yes (1)
- ○ No (2)

Q143 Images, audio and video recording will consists of interview, design and planning portion of the study. You are free to decline without affecting your remuneration. I agree to have video and audio recorded for the purpose of understanding and exploring how design, planning and validation process in the haptic storytelling takes place:

- ○ Yes (1)
- ○ No (2)

Display This Question:

If Images, audio and video recording will consists of interview, design and planning portion of the... = Yes

Q144 Video and Audio to be presented with the findings:

- ○ non anonymized video and audio (face or other identifying features will not be blurred/obscured) (1)
- ○ anonymized video and audio (face or other identifying features will be blurred/obscured) (2)
- ○ Do not use my video or audio (6)

Display This Question:

If Images, audio and video recording will consists of interview, design and planning portion of the... = Yes

Q147 Images captured to understand the steps followed in the planning, designing and validation step of the haptic storytelling will be shared with research community through seminars, conferences, presentations, and journal articles.

- ○ non anonymized image (face or other identifying features will not be blurred/obscured) (1)
- ○ anonymize image (face or other identifying features will be blurred/obscured) (2)
- ○ Dont use any of my images (3)

End of Block: Video and Data Consent Form

Start of Block: Instructions

Instructions **Instructions**

During this study you will be asked to complete the following tasks:

1. Answer a demographic questionnaire
2. Participants Complete a specific task using a Haptic device
3. Complete a survey based on your interaction with the device.
4. Complete an exit survey based on your overall experience.

1) The first section will require participants to complete some demographic questions and includes questions about their familiarity with systems that employ haptic feedback. 2) The second section will include questions related to how participants plan to add haptic feedback in the story followed by an unstructured interview session to get clear feedback and understanding of user choices. 3) The third section will require participants to answer the usability and user experience question after using the haptic storytelling tool. During this session , unstructured interview might be done based on the answer of the survey. 4) The fourth section will allow the participants to provide comments and feedback on their overall experience in the form of survey form and unstructured interview.

The study will take around 90 min to complete. If you close this website you will not be able to continue from where you left off and will have to start from the beginning of the study. An experimenter will be available to assist you if you face any technical issues or answer your queries about the study. All equipment used in the study will be sanitized.

- ☐ I have read the instructions (1)

End of Block: Instructions

Start of Block: Demographics

Demographics Intro **Let's start with a little bit about yourself !**

Please note that none of the questions will be used to identify you.

Page Break

What is your age? What is your age?

- ○ 18-20 (1)
- ○ 21-34 (2)
- ○ 35-44 (3)
- ○ 45-54 (4)
- ○ 55-64 (5)
- ○ 65+ (6)

gender What is your gender ?

- ○ Man (1)
- ○ Woman (2)
- ○ Non-binary / third gender (3)
- ○ Prefer not to say (4)
- ○ Prefer to self-describe (5) _____

Q16 **What is your current education level?**

Please specify the program you are **currently enrolled in or the highest achieved**. For example, if you are a 3rd year undergraduate student, you would select "Undergraduate", and if you are not a student but have a master's degree, you would select "Masters".

- ○ Undergraduate (1)
- ○ Masters (2)
- ○ Doctorate (3)
- ○ Others (4)

Q18 What is your educational or professional background?

- ○ Experience in Designing (1)
- ○ Experience in Art (2)
- ○ Experience in Storytelling (3)
- ○ Others (4) _____

Q19 Describe your experience is related with this user study.

_____

End of Block: Demographics

Start of Block: Demo Session

Q136 Now the researcher will give you a quick demo of the tools the you will be using in this study.

End of Block: Demo Session

Start of Block: Story Session

story Let's start with the story session !

If you have brought your own short story (in video, paper, electronic format or audio format) please hand them over to the researcher and quickly explain the story to the researcher. Otherwise researcher will give you a short children's story for this session.

By going through each lines in the story try to experiment with different haptic feedback. Please use the devices and tool provided in the demo session.

Page Break

Q21 Which haptics tools and devices did you use for your story?

- [ ] Haply (1)
- [ ] Tanvas (2)
- [ ] 3d System (3)
- [ ] Feel Craft (4)
- [ ] Worksheet (5)
- [ ] Brochure (6)
- [ ] Switch Board (7)

Q22 In which part of the story did you add haptic feedback? Please explain in detail.

_____

Q23 What are the find useful during this stage ?

_____

Q24 What were the challenges you faced during this stage?

_____

Q25 Additional Feedback

_____

End of Block: Story Session

Start of Block: Usability-Brochure

Q27 **Questionnaire for Brochure and worksheet**

While answering these question please try to provide feedback only for "Brochure and Worksheet"

Brochure It helped me be more effective

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q28 It helped me be more productive

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q29 It is useful

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q30 It gives me more control over the activities related with gathering requirements in haptics

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q31 It makes the things I want to accomplish easier to get done.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q32 It save me time when I use it

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q33 It meets my need of requirement gathering tool

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q34 It does everything I would expect it to do

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Page Break

Q60 **Questionnaire for Brochure and worksheet**

While answering these question please try to provide feedback only for "Brochure and Worksheet"

Q35 It is easy to use.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q37 It is simple to use.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q38 It is user friendly.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q39 It requires the fewest steps possible to accomplish what I want to do with it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q40 It is flexible.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q41 Using it is effortless.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q42 I can use it without written instructions.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q43 I don't notice any inconsistencies as I use it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q44 Both occasional and regular users would like it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q45 I can recover from mistakes quickly and easily.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q46 I can use it successfully every time.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Page Break

Q61 **Questionnaire for Brochure and worksheet**

While answering these question please try to provide feedback only for "Brochure and Worksheet"

Q49 I learned to use it quickly.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q50 I easily remember how to use it.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q51 It is easy to learn to use it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q52 I quickly became skillful with it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Page Break

Q62 **Questionnaire for Brochure and worksheet**

While answering these question please try to provide feedback only for "Brochure and Worksheet"

Q53 I am satisfied with it.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q54 I would recommend it to a friend.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q55 It is fun to use.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q56 It works the way I want it to work.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q57 It is wonderful.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q58 I feel I need to have it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q59 It is pleasant to use.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

End of Block: Usability-Brochure

Start of Block: Usability-HapticDevicesCollection

Q64 **Questionnaire for Haptic Device Collection**

While answering these question please try to provide feedback only for "Haptic Device Collection"

Q65 It helped me be more effective

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q66 It helped me be more productive

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q67 It is useful

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q68 It gives me more control over the activities related with gathering requirements in haptics

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q69 It makes the things I want to accomplish easier to get done.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q70 It save me time when I use it

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q71 It meets my need of requirement gathering tool

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q72 It does everything I would expect it to do

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Page Break

Q73 **Questionnaire for Haptic Device Collection**

While answering these question please try to provide feedback only for "Haptic Device Collection"

Q74 It is easy to use.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q75 It is simple to use.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q76 It is user friendly.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q77 It requires the fewest steps possible to accomplish what I want to do with it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q78 It is flexible.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q79 Using it is effortless.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q80 I can use it without written instructions.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q81 I don't notice any inconsistencies as I use it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q82 Both occasional and regular users would like it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q83 I can recover from mistakes quickly and easily.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q84 I can use it successfully every time.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Page Break

Q85 **Questionnaire for Haptic Device Collection**

While answering these question please try to provide feedback only for "Haptic Device Collection"

Q86 I learned to use it quickly.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q87 I easily remember how to use it.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q88 It is easy to learn to use it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q89 I quickly became skillful with it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Page Break

Q90 **Questionnaire for Haptic Device Collection**

While answering these question please try to provide feedback only for "Haptic Device Collection"

Q91 I am satisfied with it.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q92 I would recommend it to a friend.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q93 It is fun to use.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q94 It works the way I want it to work.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q95 It is wonderful.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q96 I feel I need to have it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q97 It is pleasant to use.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

End of Block: Usability-HapticDevicesCollection

Start of Block: Usability-SwitchBoard

Q98 **Questionnaire for Switch Board**

While answering these question please try to provide feedback only for "Swtich-Board"

Q99 It helped me be more effective

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q100 It helped me be more productive

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q101 It is useful

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q102 It gives me more control over the activities related with gathering requirements in haptics

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q103 It makes the things I want to accomplish easier to get done.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q104 It save me time when I use it

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q105 It meets my need of requirement gathering tool

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q106 It does everything I would expect it to do

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Page Break

Q107 **Questionnaire for Switch Board**

While answering these question please try to provide feedback only for "Swtich-Board"

Q108 It is easy to use.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q109 It is simple to use.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q110 It is user friendly.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q111 It requires the fewest steps possible to accomplish what I want to do with it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q112 It is flexible.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q113 Using it is effortless.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q114 I can use it without written instructions.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q115 I don't notice any inconsistencies as I use it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q116 Both occasional and regular users would like it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q117 I can recover from mistakes quickly and easily.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q118 I can use it successfully every time.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Page Break

Q119 **Questionnaire for Switch Board**

While answering these question please try to provide feedback only for "Swtich-Board"

Q120 I learned to use it quickly.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q121 I easily remember how to use it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q122 It is easy to learn to use it.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q123 I quickly became skillful with it.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Page Break

Q124 **Questionnaire for Switch Board**
While answering these question please try to provide feedback only for "Swtich-Board"

Q125 I am satisfied with it.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q126 I would recommend it to a friend.

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q127 It is fun to use.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q128 It works the way I want it to work.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q129 It is wonderful.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q130 I feel I need to have it.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

Q131 It is pleasant to use.

- Strongly disagree (4)
- Somewhat disagree (5)
- Neither agree nor disagree (6)
- Somewhat agree (7)
- Strongly agree (8)

End of Block: Usability-SwitchBoard

Start of Block: CSI Index

Q63 **Exploration**
It was easy for me to explore many different options, ideas, designs , or outcomes without a lot of tedious, repetitive interaction.

- ○ Strongly disagree (36)
- ○ Somewhat disagree (37)
- ○ Neither agree nor disagree (38)
- ○ Somewhat agree (39)
- ○ Strongly agree (40)

Q132 **Engagement**
I was very absorbed/engaged in this activity - I enjoyed it and would do it again

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q133 **Effort/Reward Tradeoff**
What I was able to produce was worth the effort required produce it

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q134 **Tool Transparency**
While I was doing the activity the tool/interface/system "disappeared", and I was able to concentrate on the activity

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

Q135 **Expressiveness**
I was able to be very expressive and creative while doing the acitvity

- ○ Strongly disagree (4)
- ○ Somewhat disagree (5)
- ○ Neither agree nor disagree (6)
- ○ Somewhat agree (7)
- ○ Strongly agree (8)

End of Block: CSI Index

UNIVERSITY OF WATERLOO

200 University Ave. W, Waterloo
ON Canada, N2L 3G1

FEEDBACK LETTER

Title of study: *Tickle Trunk: Requirement gathering tool for haptic storytelling*
Principal Investigator:

- Oliver Schneider, Assistant Professor, 1-519-888-4567 ext.38505

Student Investigator(s):

- Bibhushan Raj Joshi, Co-Investigator Dept. of Management Sciences, b3joshi@uwaterloo.ca
- Ana Lucia Diaz de Leon Derby, Co-Investigator Dept. of Systems Design Engineering, aldiazde@uwaterloo.ca
- Fiona Yang, Research Assistant, Dept. Psychology, f239yang@uwaterloo.ca

We appreciate your participation in our study and thank you for spending your time helping us with our research! The purpose of the study was to evaluate the usefulness and usability of the haptic storytelling tool. Your participation and feedback have helped inform the design of Haptic Storytelling and Requirement Gathering tool that can optimize the design process of new haptic devices.

Your identity is confidential; indeed, your name will not be included or in any other way associated, with the data collected in the study. Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time up until the point at which your data is anonymized at the end of the study. The audio and video files collected for the study will be deleted once its transcribed and coded. With permission anonymous quotations may be used in any thesis or publication that comes from this research. De-identified data may be shared publicly. Your identity will be confidential. Once all the data are collected and analyzed for the study, we plan to share the information with the research community through seminars, conferences, presentations, and journal articles.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (ORE #44482). If you have questions for the Board, contact the Office of Research Ethics, at 1- 519-888-4567 ext. 36005 or reb@uwaterloo.ca.

If you have questions about where to receive more details about the study or related research, please contact Dr. Oliver Schneider at oliver.schneider@uwaterloo.ca

We really appreciate your participation and hope that this has been an interesting experience for you!

Appendix C

CHI Workshop Study Materials and Ethics

Workshop Consent Form

Welcome to Haptic Playground Workshop!

Consent Form **Project Title:** Haptic Playground Workshop
Principal Investigator: Oliver Schneider, Assistant Professor, 1-519-888-4567 ext.38505
Student Investigators: Bibhushan Raj Joshi, PhD Student, Dept. of Management Sciences, b3joshi@uwaterloo.ca
Workshop Organizers: Sandeep Kollannur - University of Southern California, Ludwig W. Wall- University of Waterloo

We would like to invite you to participate in our study on haptic communication and team collaboration. The purpose of this study is to gain a better understanding of how interdisciplinary haptic teams work together on haptic projects.

Your participation in this study is entirely voluntary, and you may decline to participate or withdraw from the study at any time before your data is anonymized (30 days after the workshop on June 17th, 2024). **You may refuse to participate or withdraw from the study at any time during the workshop.**
The study will consist of pre- and post-workshop questionnaires which the participants will be asked to complete before and after the exercise. The questionnaires will include a series of optional inquiries to gain insight into your experiences during the exercise. The study can be conducted virtually or in-person, depending on the availability of participants. During the exercise, the organizers will document the team's collaborative efforts and relevant observations using notes.
With your permission, photos, video, and audio recordings of the participants will be collected for further observation or analysis of the discussion being made during the study. Notes will be collected to understand how participants work together in a group. You will also be asked for permission to share recordings with the research community through seminars, conferences, and journal articles. At no time will recordings be identified by name. If you agree to allow your recording to be shared publicly, you will be given the option of having identifying features blurred or obscured. You do not need to agree for your session to be recorded or shared to participate in the study. Other study data may also be shared publicly (e.g., survey results). Your name will never be associated with your individual data, and things that can identify you (e.g., identifying demographics) will be removed prior to this sharing. After completing the questionnaire, participants will be asked to join interview.

The data collected for the study will be deleted once its transcribed and coded. With permission anonymous quotations may be used in any thesis or publication that comes from this research. De-identified data may be shared publicly. Your identity will be confidential. Once all the data are collected and analyzed for the study, we plan to share the information with the research community through seminars, conferences, presentations, and journal articles.
You can request your data to be removed from the study till 30 days after the workshop is done as the data from this study will be anonymized and shared with the research community through seminars, conferences, and journal articles. Participants can always send email to bibhushan.joshi@uwaterloo.ca to know more about the progress of the study. The participants can request to be informed about the completion of data collection by providing their email address. Any data collected during the study will be stored on ECResearch, a secure network

file server for University of Waterloo Engineering faculty members. Only the researchers at the University of Waterloo involved in the study will have access to original data. For the pictures, the researcher will ask whether the participants are comfortable with including their faces for research papers and journals if not the participant's face will be blurred to avoid recognition.

You will be participating in a study that uses Qualtrics. Qualtrics has implemented technical, administrative, and physical safeguards to protect the information from loss, misuse, and unauthorized access, disclosure, alteration, or destruction. However, no internet transmission is ever fully secure or error free. Qualtrics temporarily collects your computer IP address to avoid duplicate responses in the dataset but will not collect information that could identify you personally.

TIME COMMITMENT: 10-15 minutes session

RISKS & BENEFITS: This study contains no risk. There are no direct benefits to participants. The study will help to create guideline for individual and team working in haptics.

CONFIDENTIALITY: *You will not be identified by name in any study reports. Any data gathered from this study will be stored in a secure account accessible only to the researcher.*

You understand that the researcher will ANSWER ANY QUESTIONS you have about the instructions of the procedures of this study. After participating the researcher will answer any other questions you have about this study. **Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time up until the point at which your data is anonymized (i.e., 30 days after the workshop- June 17th, 2024).** Accepting the consent indicates that you have received a copy of this consent form for your own records, and consent to participate in this study. By consenting to participate in this study, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #44481). If you have questions for the Board, contact the Office of Research Ethics, toll-free at 1-833-643-2379 (Canada and USA), 1-519-888-4440, or reb@uwaterloo.ca.

CHI is not involved in this research, nor holds any responsibility for this research project. If you have questions about the study or related research, please contact Dr. Oliver Schneider at oliver.schneider@uwaterloo.ca.

☐ **I agree to participate in the study (1)** ☐ **I do not agree to participate in this study (2)**

Q148 Media and Data Collected from the study
You will not be identified by name in any study reports. Any data gathered from this study will be stored in a secure account accessible only to the researchers.

Q142 I agree to the use of anonymous quotations in any thesis or publication that comes from this research.

☐ **Yes (1)** ☐ **No (2)**

Q236 Images captured during the workshop will be shared with research community through seminars, conferences, presentations, and journal articles. (Please let one of the organizers know if you pick second or third option)

☐ **Images captured during the interview will be shared with the research community through seminars, conferences, presentations, and journal articles. (1)**

☐ **anonymize image (face or other identifying features will be blurred/obscured) (2)**

☐ **Don't use any of my images (3)**

Q237 Pre-Exercise Questionnaires : Team information

Note: Please do not include personal information about the team members or other workshop attendees who have not consented to participate in this research (e.g., their names, profession, etc). Please kindly consult the organizers for assistance.

Q238 Team Name or ID

_____

_____

_____

_____

_____

Q239 Please provide a detailed description of your academic and professional background?

_____

_____

_____

_____

_____

Q240 What are the academic and professional background of each of your team members? (Eg: member 1- engineering undergrad with background in hardware engineering)

_____

_____

_____

_____

_____

End of Block: Before the Excercise

Start of Block: Post Excercise

Q241 **Next Section consists of Post Exercise Questionnaires**

Please move on to the next set of questionnaires only after you have completed the exercise.

End of Block: Post Excercise

Start of Block: Post Excercise

Q242 **Post Exercise Questionnaires consists of two parts**

1) Design and Communication
2) Team and Collaboration

Lets begin....

End of Block: Post Excercise

Start of Block: Design and Communication

Q243 **Design and Communication Questionnaires**

Q244 How did you design the intended haptic feedback?

_____

_____

_____

_____

_____

Q245 How did you communicate the haptic intent?

_____

_____

_____

_____

_____

Q246 What was the most interesting part? Did you learn or discover anything new during the design and communication of the intended haptic feedback?

_____

_____

_____

_____

_____

Q247 What was the most challenging part? Was anything missing in the design and communication of the haptic feedback?

_____

_____

_____

_____

_____

End of Block: Design and Communication

Start of Block: Collaboration

Q248 **Team and Collaboration**

Q249 How did you collaborate with your team, and what were everyone's roles and responsibilities?

_____

_____

_____

_____

_____

Q250 What skills and knowledge were important for teamwork? Were there any knowledge gaps?

_____

_____

_____

_____

_____

Q251 What challenges did you face while working in a team?

_____

_____

_____

_____

_____

Q252 Do you have any recommendations or best practices for teams designing and developing haptic feedback? How would you change your collaboration approach if you had to repeat the exercise?

_____

_____

_____

_____

_____

End of Block: Collaboration

Start of Block: Additional Feedback

Q253 Any additional feedback?

_____

_____

_____

_____

_____

End of Block: Additional Feedback

UNIVERSITY OF WATERLOO

200 University Ave. W, Waterloo
ON Canada, N2L 3G1

FEEDBACK LETTER

Title of study: *Inside a Haptic Team*
Principal Investigator:

- Oliver Schneider, Assistant Professor, 1-519-888-4567 ext.38505

Student Investigator(s):

- Bibhushan Raj Joshi, Co-Investigator Dept. of Management Sciences, b3joshi@uwaterloo.ca

We appreciate your participation in our study and thank you for spending your time helping us with our research! The purpose of the study was to evaluate the understand the team collaboration in a team building a haptic system. Your participation and feedback have helped inform the important guideline while building a haptic system and optimize the design and development process of new haptic devices.

Your identity is confidential; indeed, your name will not be included or in any other way associated, with the data collected in the study. Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time up until the point at which your data is anonymized at the end of the study. The participants can request to be informed about the completion of data collection by providing their email address. The audio and video files collected for the study will be deleted once its transcribed and coded. With permission anonymous quotations may be used in any thesis or publication that comes from this research. De-identified data may be shared publicly. Your identity will be confidential. Once all the data are collected and analyzed for the study, we plan to share the information with the research community through seminars, conferences, presentations, and journal articles.

his study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #44481). If you have questions for the Board, contact the Office of Research Ethics, toll-free at 1-833-643-2379 (Canada and USA), 1-519-888-4440, or reb@uwaterloo.ca.

If you have questions about where to receive more details about the study or related research, please contact Dr. Oliver Schneider at oliver.schneider@uwaterloo.ca

We really appreciate your participation and hope that this has been an interesting experience for you!

Appendix D

Scoping Review Summary Table

D.0.1 Overview Tables by Application Area

Table D.1: The table provides an overview of evaluation techniques and metrics reported in studies across the top 12 application areas identified in our dataset. It includes categories such as behavioral and performance-based evaluations, subjective and qualitative approaches, as well as specific metrics like force, perceptual qualities, temporal-spatial attributes, and cognitive or emotional measures metioned in Table 6.3 and Table 6.2. Superscripts refer to variable codes defined in Appendix in Table D.8; each code maps to the full list of paper identifiers contributing to the corresponding value.

Application Areas	Reporting Category	Details(paper count)

Virtual Reality (n = 157)	Evaluation Technique	Behavioral & Performance (42)[et1-1]; Physiological & Psychophysical (19)[et2-1]; Qualitative&/Exploratory (42)[et3-1]; Subjective (103)[et4-1]; Not Reported (104)[et5-1];
	Metrics Used	Force-Related Measures (13)[mu1-1]; Perceptual Qualities (22)[mu2-1]; Performance & Task Metrics (43)[mu3-1]; Physical Interaction Metrics (8)[mu4-1]; Temporal & Spatial Measures (41)[mu5-1]; Cognitive & Emotional Metrics (6)[mu6-1]; Not Reported (102)[mu7-1];
Wearables (n = 59)	Evaluation Technique	Behavioral & Performance (20)[et1-2]; Physiological & Psychophysical (4)[et2-2]; Qualitative & Exploratory (16)[et3-2]; Subjective (34)[et4-2]; Not Reported (36)[et5-2];

	Metrics Used	Force-Related Measures (4)[mu1-2]; Perceptual Qualities (14)[mu2-2]; Performance & Task Metrics (27)[mu3-2]; Temporal & Spatial Measures (18)[mu5-2]; Not Reported (38)[mu7-2];
Robotics (n = 52)	Evaluation Technique	Behavioral & Performance (21)[et1-3]; Physiological & Psychophysical (2)[et2-3]; Qualitative & Exploratory (7)[et3-3]; Subjective (30)[et4-3]; Not Reported (33)[et5-3];
	Metrics Used	Force-Related Measures (8)[mu1-3]; Perceptual Qualities (9)[mu2-3]; Performance & Task Metrics (23)[mu3-3]; Physical Interaction Metrics (3)[mu4-3]; Temporal & Spatial Measures (14)[mu5-3]; Cognitive & Emotional Metrics (8)[mu6-3]; Not Reported (27)[mu7-3];

Accessibility (n = 40)	Evaluation Technique	Behavioral & Performance(20)[et1-4]; Physiological & Psychophysical (1)[et2-4]; Qualitative & Exploratory (15)[et3-4]; Subjective (17)[et4-4]; Not Reported (21)[et5-4];
	Metrics Used	Force-Related Measures (29)[mu1-4]; Perceptual Qualities (3)[mu2-4]; Performance & Task Metrics (2)[mu3-4]; Physical Interaction Metrics (18)[mu4-4]; Temporal & Spatial Measures (2)[mu5-4]; Not Reported (23)[mu7-4];
Teleoperation (n = 40)	Evaluation Technique	Behavioral & Performance (18)[et1-5]; Qualitative & Exploratory (4)[et3-5]; Subjective (21)[et4-5]; Not Reported (30)[et5-5];

	Metrics Used	Force-Related Measures (7)[mu1-5]; Perceptual Qualities (5)[mu2-5]; Performance & Task Metrics (20)[mu3-5]; Physical Interaction Metrics (5)[mu4-5]; Temporal & Spatial Measures (16)[mu5-5]; Cognitive & Emotional Metrics (2)[mu6-5]; Not Reported (27)[mu7-5];
Medical (n = 30)	Evaluation Technique	Behavioral & Performance (14)[et1-6]; Physiological & Psychophysical (4)[et2-6]; Qualitative & Exploratory (1)[et3-6]; Subjective (16)[et4-6]; Not Reported (19)[et5-6];
	Metrics Used	Force-Related Measures (5)[mu1-6]; Performance & Task Metrics (17)[mu3-6]; Physical Interaction Metrics (3)[mu4-6]; Temporal & Spatial Measures (11)[mu5-6]; Not Reported (14)[mu7-6];

Augmented Reality (n = 26)	Evaluation Technique	Behavioral & Performance (3)[et1-7]; Physiological & Psychophysical (2)[et2-7]; Qualitative & Exploratory (8)[et3-7]; Subjective (19)[et4-7]; Not Reported (21)[et5-7];
	Metrics Used	Force-Related Measures (3)[mu1-7]; Perceptual Qualities (3)[mu2-7]; Performance & Task Metrics (8)[mu3-7]; Physical Interaction Metrics (1)[mu4-7]; Temporal & Spatial Measures (8)[mu5-7]; Cognitive & Emotional Metrics (1)[mu6-7]; Not Reported (17)[mu7-7];
Virtual Environment (n = 25)	Evaluation Technique	Behavioral & Performance (6)[et1-8]; Physiological & Psychophysical (1)[et2-8]; Qualitative & Exploratory (3)[et3-8]; Subjective (12)[et4-8]; Not Reported (17)[et5-8];

	Metrics Used	Force-Related Measures (2)[mu1-8]; Perceptual Qualities (4)[mu2-8]; Performance & Task Metrics (5)[mu3-8]; Physical Interaction Metrics (2)[mu4-8]; Temporal & Spatial Measures (6)[mu5-8]; Cognitive & Emotional Metrics (1)[mu6-8]; Not Reported (19)[mu7-8];
Gaming (n = 25)	Evaluation Technique	Behavioral & Performance (4)[et1-9]; Physiological & Psychophysical (3)[et2-9]; Qualitative & Exploratory (10)[et3-9]; Subjective (20)[et4-9]; Not Reported (20)[et5-9];
	Metrics Used	Force-Related Measures (2)[mu1-9]; Perceptual Qualities (5)[mu2-9]; Performance & Task Metrics (7)[mu3-9]; Physical Interaction Metrics (1)[mu4-9]; Temporal & Spatial Measures (10)[mu5-9]; Cognitive & Emotional Metrics (1)[mu6-9]; Not Reported (18)[mu7-9];

Affective Computing (n = 17)	Evaluation Technique	Behavioral & Performance (5)[et1-10]; Physiological & Psychophysical (2)[et2-10]; Subjective (5)[et4-10]; Not Reported (9)[et5-10];
	Metrics Used	Force-Related Measures (3)[mu1-10]; Perceptual Qualities (2)[mu2-10]; Performance & Task Metrics (6)[mu3-10]; Temporal & Spatial Measures (2)[mu5-10]; Cognitive & Emotional Metrics (3)[mu6-10]; Not Reported (6)[mu7-10];
Rehabilitation (n = 17)	Evaluation Technique	Behavioral & Performance(6)[et1-11]; Qualitative & Exploratory (1)[et3-11]; Subjective (3)[et4-11]; Not Reported (11)[et5-11];
	Metrics Used	Force-Related Measures (1)[mu1-11]; Perceptual Qualities (2)[mu2-11]; Performance & Task Metrics (8)[mu3-11]; Physical Interaction Metrics (1)[mu4-11]; Temporal & Spatial Measures (11)[mu5-11]; Not Reported (8)[mu7-11];

Training (n = 16)	Evaluation Technique	Behavioral & Performance (10)[et1-12]; Physiological & Psychophysical (1)[et2-12]; Qualitative & Exploratory (2)[et3-12]; Subjective (12)[et4-12]; Not Reported (10)[et5-12];
	Metrics Used	Force-Related Measures (6)[mu1-12]; Perceptual Qualities (2)[mu2-12]; Performance & Task Metrics (4)[mu3-12]; Physical Interaction Metrics (1)[mu4-12]; Temporal & Spatial Measures (2)[mu5-12]; Not Reported (9)[mu7-12];

Table D.2: The table provides an overview of participant characteristics reported in studies across the top 12 application areas identified in our dataset. It includes information on target populations, age and gender reporting practices, and sample size distributions. Superscripts refer to variable codes defined in Appendix in Table D.6; each code maps to the full list of paper identifiers contributing to the corresponding value. "HoH" refers to Hard of Hearing. Sample size categories are defined as: Small (<10), Medium (10–29), Large (30–99), and Very Large (≥100).

Application Areas	**Reporting Category**	**Details(paper count)**

Virtual Reality (n = 157)	Target Population	Elderly (1)[tp1-1]; Gamers (1)[tp2-1]; General Population (15)[tp3-1]; Blind/Low Vision (3)[tp4-1]; Deaf/HoH (2)[tp5-1]; Sighted Users (2)[tp6-1]; Not-Specified (80)[tp7-1]; Nurses (1)[tp8-1]; Other (47)[tp9-1]; Pilot (3)[tp10-1]; Student (25)[tp11-1]; University Staff (13)[tp12-1];
	Age Reporting	Mean and or SD (37)[ar1-1]; Mean, SD and or Range (67)[ar2-1]; Not Reported (19)[ar3-1]; Range Only (37)[ar4-1];
	Gender Reporting	Male (122)[gr1-1]; Female (129)[gr2-1]; Open Ended (2)[gr3-1]; Not Reported (20)[gr4-1];
	Sample Size	Small (39)[ss1-1]; Medium (79)[ss2-1]; Large (19)[ss3-1]; Very Large (0); Not Reported (22)[ss5-1];

Wearables (n = 59)	Target Population	Elderly (1)[tp1-2]; General Population (3)[tp2-2]; Hospital Patients (1)[tp3-2]; Blind/Low Vision (1)[tp4-2]; Sighted Users (40)[tp6-2]; Other (24)[tp8-2]; Pilot (1)[tp9-2]; Student (3)[tp10-2]; University Staff (2)[tp12-2];
	Age Reporting	Mean and or SD (19)[ar1-2]; Mean, SD and or Range (15)[ar2-2]; Not Reported (7)[ar3-2]; Range Only (19)[ar4-2];
	Gender Reporting	Male (41)[gr1-2]; Female (49)[gr2-2]; Open Ended (2)[gr3-2]; Not Reported (10)[gr4-2];
	Sample Size	Small (18)[ss1-2]; Medium (27)[ss2-2]; Large (3)[ss3-2]; Very Large (1)[ss4-2]; Not Reported (10)[ss5-2];
Robotics (n = 52)	Target Population	General Population (12)[tp2-3]; Motor Disabilities (1)[tp13-3]; Sighted Users (1)[tp6-3]; Not-Specified (21)[tp7-3]; Other (19)[tp8-3]; Student (3)[tp10-3]; University Staff (3)[tp12-3]; Expert tp20-3

	Age Reporting	Mean and or SD (11)[ar1-3]; Mean, SD and or Range (13)[ar2-3]; Not Reported (15)[ar3-3]; Range Only (15)[ar4-3];
	Gender Reporting	Male (37)[gr1-3]; Female (34)[gr2-3]; Open Ended (1)[gr3-3]; Not Reported (13)[gr4-3];
	Sample Size	Small (10)[ss1-3]; Medium (27)[ss2-3]; Large (1)[ss3-3]; Very Large (2)[ss4-3]; Not Reported (13)[ss5-3];
Accessibility (n = 40)	Target Population	Children (2)[tp14-4]; General Population (1)[tp2-4]; Blind/Low Vision (15)[tp4-4]; Blind (2)[tp15-4]; Motor Disabilities (2)[tp13-4]; Deaf/HoH (3)[tp5-4]; Sighted Users (2)[tp6-4]; Not-Specified (7)[tp7-4]; Other (16)[tp8-4]; Student (5)[tp10-4]; Teachers/Educators (1)[tp16-4]; University Staff (4)[tp12-4];
	Age Reporting	Mean and or SD (7)[ar1-4]; Mean, SD and or Range (14)[ar2-4]; Not Reported (6)[ar3-4]; Range Only (14)[ar4-4];

	Gender Reporting	Male (31)[gr1-4]; Female (29)[gr2-4]; Open Ended (1)[gr3-4]; Not Reported (9)[gr4-4];
	Sample Size	Small (10)[ss1-4]; Medium (18)[ss2-4]; Large (1)[ss3-4]; Very Large (1)[ss4-4]; Not Reported (10)[ss5-4];
Teleoperation (n = 40)	Target Population	General Population (7)[tp2-5]; Motor Disabilities (1)[tp13-5]; Sighted Users (1)[tp6-5]; Not-Specified (19)[tp7-5]; Other (13)[tp8-5]; Student (1)[tp10-5]; University Staff (1)[tp12-5];
	Age Reporting	Mean and or SD (8)[ar1-5]; Mean, SD and or Range (5)[ar2-5]; Not Reported (12)[ar3-5]; Range Only (15)[ar4-5];
	Gender Reporting	Male (27)[gr1-5]; Female (26)[gr2-5]; Open Ended (0); Not Reported (11)[gr4-5];
	Sample Size	Small (6)[ss1-5]; Medium (22)[ss2-5]; Large (1)[ss3-5]; Very Large (0); Not Reported (11)[ss5-5];

Medical (n = 30)	Target Population	Children (1)[tp14-6]; Doctors (1)[tp17-6]; Elderly (2)[tp1-6]; General Population (4)[tp2-6]; Motor Disabilities (1)[tp13-6]; Not-Specified (9)[tp7-6]; Nurses (1)[tp8-6]; Other (14)[tp8-6]; Student (4)[tp10-6]; University Staff (1)[tp12-6];
	Age Reporting	Mean and or SD (3)[ar1-6]; Mean, SD and or Range (5)[ar2-6]; Not Reported (8)[ar3-6]; Range Only (14)[ar4-6];
	Gender Reporting	Male (19)[gr1-6]; Female (18)[gr2-6]; Open Ended (0); Not Reported (9)[gr4-6];
	Sample Size	Small (6)[ss1-6]; Medium (9)[ss2-6]; Large (6)[ss3-6]; Very Large (0); Not Reported (9)[ss5-6];
Augmented Reality (n = 26)	Target Population	Children (1)[tp14-7]; General Population (5)[tp2-7]; Sighted Users (1)[tp6-7]; Not-Specified (14)[tp7-7]; Other (12)[tp8-7]; Student (3)[tp10-7]; University Staff (2)[tp12-7];

	Age Reporting	Mean and or SD (10)[ar1-7]; Mean, SD and or Range (7)[ar2-7]; Not Reported (3)[ar3-7]; Range Only (8)[ar4-7];
	Gender Reporting	Male (17)[gr1-7]; Female (19)[gr2-7]; Open Ended (1)[gr3-7]; Not Reported (7)[gr4-7];
	Sample Size	Small (7)[ss1-7]; Medium (14)[ss2-7]; Large (0); Very Large (0); Not Reported (7)[ss5-7];
Virtual Environment (n = 25)	Target Population	Elderly (1)[tp1-8]; General Population (1)[tp2-8]; Blind/Low Vision (1)[tp4-8]; Motor Disabilities (1)[tp13-8]; Deaf/HoH (1)[tp5-8]; Not-Specified (13)[tp7-8]; Other (8)[tp8-8]; Student (2)[tp10-8]; University Staff (3)[tp12-8];
	Age Reporting	Mean and or SD (6)[ar1-8]; Mean, SD and or Range (9)[ar2-8]; Not Reported (4)[ar3-8]; Range Only (7)[ar4-8];
	Gender Reporting	Male (18)[gr1-8]; Female (19)[gr2-8]; Open Ended (0); Not Reported (6)[gr4-8];

	Sample Size	Small (6)[ss1-8]; Medium (10)[ss2-8]; Large (2)[ss3-8]; Very Large (0); Not Reported (8)[ss5-8];
Gaming (n = 25)	Target Population	Gamers (1)[tp18-9]; Blind/Low Vision (1)[tp4-9]; Not-Specified (14)[tp7-9]; Other (7)[tp8-9]; Pilot (1)[tp9-9]; Student (4)[tp10-9]; University Staff (4)[tp12-9];
	Age Reporting	Mean and or SD (10)[ar1-9]; Mean, SD and or Range (7)[ar2-9]; Not Reported (0); Range Only (8)[ar4-9];
	Gender Reporting	Male (18)[gr1-9]; Female (24)[gr2-9]; Open Ended (1)[gr3-9]; Not Reported (1)[gr4-9];
	Sample Size	Small (8)[ss1-9]; Medium (12)[ss2-9]; Large (4)[ss3-9]; Very Large (0); Not Reported (1)[ss5-9];
Affective Computing (n = 17)	Target Population	General Population (9)[tp2-10]; Sighted Users (1)[tp6-10]; Not-Specified (4)[tp7-10]; Other (1)[tp8-10]; Student (2)[tp10-10]; University Staff (2)[tp12-10];

	Age Reporting	Mean and or SD (5)[ar1-10]; Mean, SD and or Range (5)[ar2-10]; Not Reported (5)[ar3-10]; Range Only (5)[ar4-10];
	Gender Reporting	Male (10)[gr1-10]; Female (11)[gr2-10]; Open Ended (1)[gr3-10]; Not Reported (9)[gr4-10];
	Sample Size	Small (2)[ss1-10]; Medium (7)[ss2-10]; Large (1)[ss3-10]; Very Large (1)[ss4-10]; Not Reported (9)[ss5-10];
Rehabilitation (n = 17)	Target Population	General Population (2)[tp2-11]; Hospital Patients (1)[tp3-11]; Not-Specified (6)[tp7-11]; Other (7)[tp8-11]; Student (1)[tp10-11]; University Staff (1)[tp12-11];
	Age Reporting	Mean and or SD (6)[ar1-11]; Mean, SD and or Range (2)[ar2-11]; Not Reported (3)[ar3-11]; Range Only (6)[ar4-11];
	Gender Reporting	Male (10)[gr1-11]; Female (7)[gr2-11]; Open Ended (0); Not Reported (6)[gr4-11];
	Sample Size	Small (7)[ss1-11]; Medium (4)[ss2-11]; Large (0); Very Large (0); Not Reported (6)[ss5-11];

Training (n = 16)	Target Population	Children (1)[tp14-12]; Elderly (1)[tp1-12]; General Population (1)[tp2-12]; Health Professionals (1)[tp19-12]; Not-Specified (7)[tp7-12]; Nurses (1)[tp8-12]; Other (3)[tp8-12]; Pilot (1)[tp9-12]; Student (3)[tp10-12]; University Staff (2)[tp12-12];
	Age Reporting	Mean and or SD (3)[ar1-12]; Mean, SD and or Range (5)[ar2-12]; Not Reported (4)[ar3-12]; Range Only (5)[ar4-12];
	Gender Reporting	Male (10)[gr1-12]; Female (11)[gr2-12]; Open Ended (0); Not Reported (6)[gr4-12];
	Sample Size	Small (4)[ss1-12]; Medium (5)[ss2-12]; Large (2)[ss3-12]; Very Large (0); Not Reported (6)[ss5-12];

Table D.3: The table provides an overview of study characteristics, including ethics reporting, study type, methodology, study design, duration, and activity type, across the top 12 application areas identified in our dataset. Superscripts refer to variable codes defined in Appendix in Table D.5; each code maps to the full list of paper identifiers contributing to the corresponding value.

Application Area	**Characteristic**	**Summary (Count)**
	Ethics	Yes (53)$^{\text{ethY1}}$; No (106)$^{\text{ethN2}}$
Virtual Reality (n = 160)	Study Type	Qualitative (7)$^{\text{st1}}$; Quantitative (73)$^{\text{st2}}$ Both (40)$^{\text{st3}}$; Not Applicable (3)$^{\text{st4}}$
	Methodology	Comparative (3)$^{\text{meth2}}$, Experimental (15)$^{\text{meth4}}$, Feasibility (5)$^{\text{meth5}}$, Not Reported (94)$^{\text{meth8}}$, Others (28)$^{\text{meth9}}$, Pilot (18)$^{\text{meth10}}$, Preliminary Study (19)$^{\text{meth11}}$, Survey (1)$^{\text{meth13}}$
	Study Design	Between Participants (17)$^{\text{sd1}}$, Within Participants (106)$^{\text{sd2}}$, Not Sure (4)$^{\text{sd3}}$, Not Reported (41)$^{\text{sd5}}$

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Application Area	Characteristic	Summary (Count)
	Study Duration	<10min (2)[dru1], 10–30min (14)[dru2], 30–60min (18)[dru3], 1–2hr (30)[dru4], 2–4hr (5)[dru5], >24hr (1)[dru7]

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Application Area	Characteristic	Summary (Count)
	Activity	Aseembly (2)[act2], Driving (1)[act5], Object Exploration (13)[act6], Gaming (12)[act8], Gesture (5)[act9], Holding Objects (17)[act10], Medical Procedures (4)[act11], Moving Objects (9)[act12], Navigational Task (5)[act14], Not Reported (1)[act15], Object Recognition (7)[act17], Others (56)[act18], No Task (4)[act19], Pattern Recognition (10)[act20], Pressing Button (6)[act21], Product Evaluation (4)[act22], Robot Interaction (2)[act24], Scanning Texture (7)[act26], Sitting (12)[act27], Social Interaction (1)[act28], Sports (6)[act29], Surgical Training (3)[act30], Typing (1)[act31], VR Ficitional (30)[act32], VR Non-Fictional (62)[act33], Walking (3)[act34]

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Application Area	Characteristic	Summary (Count)
	Ethics	Yes (30)^{ethY3}; No (30)^{ethN3}
Wearables (n = 59)	Study Type	Qualitative (2)$^{st1\text{-}3}$; Quantitative (36)$^{st2\text{-}3}$ Both (11)$^{st3\text{-}3}$; Not Applicable (0)$^{st4\text{-}3}$
	Methodology	Case Study (1)$^{meth1\text{-}3}$, Comparative (1)$^{meth2\text{-}3}$, Ethnographic (1)$^{meth3\text{-}3}$, Experimental (8)$^{meth4\text{-}3}$, Not Reported (35)$^{meth8\text{-}3}$, Others (11)$^{meth9\text{-}3}$, Pilot (3)$^{meth10\text{-}3}$, Preliminary Study (5)$^{meth11\text{-}3}$, Survey (1)$^{meth13\text{-}3}$
	Study Design	Between Participants (8)$^{sd1\text{-}3}$, Within Participants (41)$^{sd2\text{-}3}$, Not Sure (1)$^{sd3\text{-}3}$, Others (1)$^{sd4\text{-}3}$, Not Reported (11)$^{sd5\text{-}3}$
	Study Duration	10–30min (2)$^{dru2\text{-}3}$, 30–60min (6)$^{dru3\text{-}3}$, 1–2hr (13)$^{dru4\text{-}3}$, 2–4hr (1)$^{dru5\text{-}3}$, 4–24hr (1)$^{dru6\text{-}3}$, >24hr (3)$^{dru7\text{-}3}$

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Application Area	Characteristic	Summary (Count)
	Activity	Object Exploration (3)[act6-3], Geometric Exploration (1)[act7-3], Gaming (1)[act8-3], Gesture (3)[act9-3], Holding Objects (5)[act10-3], Moving Objects (1)[act12-3], Navigational Task (3)[act14-3], Object Recognition (2)[act17-3], Others (39)[act18-3], No Task (3)[act19-3], Pattern Recognition (8)[act20-3], Pressing Button (2)[act21-3], Product Evaluation (6)[act22], Reading (1)[act23-3], Robot Interaction (1)[act24-3], Running (1)[act25-3], Scanning Texture (3)[act26-3], Sitting (6)[act27-3], Typing (1)[act31-3], VR Ficitional (3)[act32-3], VR Non-Fictional (4)[act33-3], Walking (5)[act34-3]
	Ethics	Yes (28)[ethY4]; No (26)[ethN4]

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Robotics (n = 53)

Application Area	Characteristic	Summary (Count)
	Study Type	Qualitative (3)[st1-4]; Quantitative (23)[st2-4] Both (20)[st3-4]; Not Applicable (0)[st4-4]
	Methodology	Case Study (1)[meth1-4], Experimental (7)[meth4-4], Lab Study (1)[meth6-4], Not Reported (22)[meth8-4], Others (2)[meth9-4], Pilot (2)[meth10-4], Preliminary Study (16)[meth11-4], Remote (1)[meth12-4]
	Study Design	Between Participants (9)[sd1-4], Within Participants (27)[sd2-4], Not Sure (3)[sd3-4], Others (1)[sd4-4], Not Reported (19)[sd5-4]
	Study Duration	<10min (4)[dru1-4], 10–30min (4)[dru2-4], 30–60min (4)[dru3-4], 1–2hr (7)[dru4-4], 2–4hr (1)[dru5-4], >24hr (1)[dru7-4]

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Application Area	Characteristic	Summary (Count)
	Activity	Aseembly (3)[act2-4], Object Exploration (5)[act6-4], Geometric Exploration (1)[act7-4], Gaming (2)[act8-4], Holding Objects (3)[act10-4], Moving Objects (4)[act12-4], Musical Instrument Interaction (1)[act13-4], Navigational Task (5)[act14-4], Not Reported (1)[act15-4], Object Recognition (1)[act17-4], Others (22)[act18-4], No Task (3)[act19-4], Pattern Recognition (1)[act20-4], Pressing Button (1)[act21-4], Product Evaluation (2)[act22-4], Robot Interaction (9)[act24-4], Scanning Texture (2)[act26-4], Sitting (4)[act27-4], Surgical Training (2)[act30-4], VR Ficitional (7)[act32-4], VR Non-Fictional (4)[act33-4], Walking (3)[act34-4], Watching Video (2)[act35-4]

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Application Area	Characteristic	Summary (Count)
	Ethics	Yes (19)^{ethY5}; No (22)^{ethN5}
Accessibility (n = 40)	Study Type	Qualitative (2)$^{st1\text{-}5}$; Quantitative (20)$^{st2\text{-}5}$ Both (15)$^{st3\text{-}5}$; Not Applicable (0)$^{st4\text{-}5}$
	Methodology	Case Study (1)$^{meth1\text{-}5}$, Comparative (2)$^{meth2\text{-}5}$, Experimental (3)$^{meth4\text{-}5}$, Not Reported (25)$^{meth8\text{-}5}$, Others (8)$^{meth9\text{-}5}$, Pilot (4)$^{meth10\text{-}5}$, Preliminary Study (2)$^{meth11\text{-}5}$, Remote (1)$^{meth12\text{-}5}$, Survey (1)$^{meth13\text{-}5}$, WOZ (1)$^{meth14\text{-}5}$
	Study Design	Between Participants (5)$^{sd1\text{-}5}$, Within Participants (23)$^{sd2\text{-}5}$, Not Sure (1)$^{sd3\text{-}5}$, Others (1)$^{sd4\text{-}5}$, Not Reported (13)$^{sd5\text{-}5}$
	Study Duration	10–30min (4)$^{dru2\text{-}5}$, 30–60min (3)$^{dru3\text{-}5}$, 1–2hr (5)$^{dru4\text{-}5}$, 2–4hr (2)$^{dru5\text{-}5}$, 4–24hr (2)$^{dru6\text{-}5}$, >24hr (3)$^{dru7\text{-}5}$

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Application Area	Characteristic	Summary (Count)
	Activity	Braille Reading (1)[act3-5], Object Exploration (3)[act6-5], Geometric Exploration (1)[act7-5], Gaming (3)[act8-5], Moving Objects (2)[act12-5], Navigational Task (8)[act14-5], Object Recognition (4)[act17-5], Others (21)[act18-5], Pattern Recognition (8)[act20-5], Pressing Button (3)[act21-5], Product Evaluation (1)[act22-5], Running (1)[act25-5], Scanning Texture (1)[act26-5], Sitting (4)[act27-5], Sports (1)[act29-5], Typing (1)[act31-5], VR Non-Fictional (1)[act33-5], Walking (6)[act34-5]
	Ethics	Yes (22)[ethY6]; No (18)[ethN6]
Teleoperation (n = 40)	Study Type	Qualitative (1)[st1-6]; Quantitative (24)[st2-6] Both (9)[st3-6]; Not Applicable (0)[st4-6]

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Application Area	Characteristic	Summary (Count)
	Methodology	Experimental (6)[meth4-6], Lab Study (1)[meth6-6], Not Reported (21)[meth8-6], Others (4)[meth9-6], Pilot (1)[meth10-6], Preliminary Study (7)[meth11-6]
	Study Design	Between Participants (3)[sd1-6], Within Participants (26)[sd2-6], Not Sure (1)[sd3-6], Others (0)[sd4-6], Not Reported (12)[sd5-6]
	Study Duration	<10min (3)[dru1-6], 10–30min (1)[dru2-6], 30–60min (1)[dru3-6], 1–2hr (3)[dru4-6], >24hr (1)[dru7-6]

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Application Area	Characteristic	Summary (Count)
	Activity	Aseembly (2)[act2-6], Driving (1)[act5-6], Object Exploration (1)[act6-6], Gesture (1)[act9-6], Holding Objects (6)[act10-6], Moving Objects (8)[act12-6], Navigational Task (5)[act14-6], Not Reported (2)[act15-6], Object Recognition (2)[act17-6], Others (16)[act18-6], No Task (1)[act19-6], Pattern Recognition (3)[act20-6], Robot Interaction (10)[act24-6], Scanning Texture (1)[act26-6], Sitting (1)[act27-6], Surgical Training (1)[act30-6], VR Ficitional (2)[act32-6], VR Non-Fictional (5)[act33-6], Walking (1)[act34-6]
Medical (n = 30)	Ethics	Yes (18)[ethY7]; No (12)[ethN7]
	Study Type	Qualitative (1)[st1-7]; Quantitative (17)[st2-7] Both (8)[st3-7]; Not Applicable (0)[st4-7]

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Application Area	Characteristic	Summary (Count)
	Methodology	Case Study (1)[meth1-7], Experimental (4)[meth4-7], Not Reported (14)[meth8-7], Others (4)[meth9-7], Pilot (2)[meth10-7], Preliminary Study (3)[meth11-7]
	Study Design	Between Participants (5)[sd1-7], Within Participants (13)[sd2-7], Not Sure (2)[sd3-7], Others (1)[sd4-7], Not Reported (10)[sd5-7]
	Study Duration	10–30min (1)[dru2-7], 30–60min (1)[dru3-7], 1–2hr (4)[dru4-7], >24hr (3)[dru7-7]

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Application Area	Characteristic	Summary (Count)
	Activity	Dental Procedure (1)[act4-7], Object Exploration (1)[act6-7], Geometric Exploration (1)[act7-7], Gesture (1)[act9-7], Medical Procedures (8)[act11-7], Moving Objects (1)[act12-7], Musical Instrument Interaction (1)[act13-7], Navigational Task (3)[act14-7], Others (8)[act18-7], Pattern Recognition (2)[act20-7], Product Evaluation (1)[act22-7], Sitting (1)[act27-7], Surgical Training (7)[act30-7], VR Non-Fictional (3)[act33-7], Walking (2)[act34-7]
Augmented Reality (n = 27)	Ethics	Yes (11)[ethY8]; No (16)[ethN8]
	Study Type	Qualitative (1)[st1-8]; Quantitative (10)[st2-8] Both (9)[st3-8]; Not Applicable (0)[st4-8]

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Application Area	Characteristic	Summary (Count)
	Methodology	Experimental (1)[meth4-8], Feasibility (2)[meth5-8], Not Reported (14)[meth8-8], Others (5)[meth9-8], Pilot (1)[meth10-8], Preliminary Study (5)[meth11-8], Survey (1)[meth13-8]
	Study Design	Between Participants (2)[sd1-8], Within Participants (18)[sd2-8], Not Sure (1)[sd3-8], Not Reported (6)[sd5-8]
	Study Duration	30–60min (2)[dru3-8], 1–2hr (5)[dru4-8], 2–4hr (3)[dru5-8]

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Application Area	Characteristic	Summary (Count)
	Activity	Object Exploration (3)[act6-8], Gaming (4)[act8-8], Holding Objects (2)[act10-8], Moving Objects (1)[act12-8], Navigational Task (1)[act14-8], Others (16)[act18-8], Pattern Recognition (2)[act20-8], Pressing Button (1)[act21-8], Product Evaluation (2)[act22-8], Scanning Texture (2)[act26-8], Sitting (1)[act27-8], VR Ficitional (3)[act32-8], VR Non-Fictional (3)[act33-8], Walking (2)[act34-8], Writing (1)[act36-8]
	Ethics	Yes (6)[ethY9]; No (19)[ethN9]
Virtual Environment (n = 26)	Study Type	Qualitative (2)[st1-9]; Quantitative (17)[st2-9] Both (3)[st3-9]; Not Applicable (0)[st4-9]

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Application Area	Characteristic	Summary (Count)
	Methodology	Case Study (1)[meth1-9], Experimental (3)[meth4-9], Feasibility (1)[meth5-9], Not Reported (12)[meth8-9], Others (2)[meth9-9], Pilot (6)[meth10-9], Preliminary Study (3)[meth11-9]
	Study Design	Between Participants (2)[sd1-9], Within Participants (18)[sd2-9], Not Sure (2)[sd3-9], Others (1)[sd4-9], Not Reported (4)[sd5-9]
	Study Duration	<10min (1)[dru1-9], 10–30min (2)[dur2-9], 30–60min (3)[dur3-9], 1–2hr (2)[dur4-9], 2–4hr (2)[dur5-9], >24hr (1)[dur7-9]

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Application Area	Characteristic	Summary (Count)
	Activity	Object Exploration (5)[act6-9], Geometric Exploration (1)[act7-9], Gaming (1)[act8-9], Gesture (1)[act9-9], Holding Objects (6)[act10-9], Navigational Task (3)[act14-9], Others (8)[act18-9], No Task (1)[act19-9], Pattern Recognition (1)[act20-9], Pressing Button (1)[act21-9], Sitting (4)[act27-9], Sports (1)[act29-9], Surgical Training (1)[act30-9], VR Ficitional (4)[act32-9], VR Non-Fictional (10)[act33-9], Walking (1)[act34-9]
Gaming (n = 25)	Ethics	Yes (8)[ethY10]; No (17)[ethN10]
	Study Type	Qualitative (3)[st1-10]; Quantitative (12)[st2-10] Both (7)[st3-10]; Not Applicable (0)[st4-10]

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Application Area	Characteristic	Summary (Count)
	Methodology	Case Study (0)[meth1-10]; Comparative Study (0)[meth2-10]; Ethnographic Study (1)[meth3-10] Ethnographic (1)[meth3-10], Experimental (1)[meth4-10], Not Reported (18)[meth8-10], Others (5)[meth9-10], Pilot (2)[meth10-10], Preliminary Study (2)[meth11-10]
	Study Design	Between Participants (3)[sd1-10], Within Participants (17)[sd2-10], Not Reported (6)[sd5-10]
	Study Duration	10–30min (3)[dur2-10], 30–60min (3)[dur3-10], 1–2hr (4)[dur4-10], 2–4hr (1)[dur5-10], >24hr (1)[dur7-10]

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Application Area	Characteristic	Summary (Count)
	Activity	Object Exploration (1)[act6-10], Gaming (10)[act8-10], Holding Objects (3)[act10-10], Moving Objects (2)[act12-10], Object Recognition (2)[act17-10], Others (11)[act18-10], Pattern Recognition (3)[act20-10], Product Evaluation (3)[act22-10], Scanning Texture (1)[act26-10], Sitting (4)[act27-10], Sports (3)[act29-10], VR Ficitional (5)[act32-10], VR Non-Fictional (9)[act33-10], Walking (1)[act34-10]
	Ethics	Yes (9)[ethY11]; No (10)[ethN11]
Affective Computing (n = 20)	Study Type	Qualitative (3)[st1-11]; Quantitative (2)[st2-10] Both (11)[st3-10]; Not Applicable (0)[st4-10]

(continued on next page)

Application Area	Characteristic	Summary (Count)
	Methodology	Comparative (2)[meth2-11], Experimental (5)[meth4-11], Others (2)[meth9-11], Preliminary Study (12)[meth11-11]
	Study Design	Between Participants (0)[sd1-11], Within Participants (7)[sd2-11], Not Sure (0)[sd3-11], Others (0)[sd4-11], Not Reported (12)[sd5-11]
	Study Duration	<10min (1)[dru1-11], 10–30min (1)[dur2-11], 30–60min (1)[dur3-11], 1–2hr (2)[dur4-11], 2–4hr (1)[dur5-11], 4–24hr (2)[dur6-11]

(continued on next page)

Application Area	Characteristic	Summary (Count)
	Activity	Object Exploration (1)[act6-11], Gesture (2)[act9-11], Holding Objects (1)[act10-11], Navigational Task (3)[act14-11], Not Sure (1)[act16-11], Others (8)[act18-11], No Task (2)[act19-11], Robot Interaction (2)[act24-11], Scanning Texture (2)[act26-11], Sitting (1)[act27-11], VR Ficitional (1)[act32-11], VR Non-Fictional (1)[act33-11]
Rehabilitation (n = 17)	Ethics	Yes (15)[ethY12]; No (2)[ethN12]
	Study Type	Qualitative (0)[st1-10]; Quantitative (11)[st2-10] Both (4)[st3-10]; Not Applicable (1)[st4-10]
	Methodology	Not Reported (8)[meth8-12], Others (1)[meth9-12], Pilot (4)[meth10-12], Preliminary Study (6)[meth11-12]

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Application Area	Characteristic	Summary (Count)
	Study Design	Between Participants (2)[sd1-12], Within Participants (12)[sd2-12], Not Sure (1)[sd3-12], Others (0)[sd4-12], Not Reported (3)[sd5-12]
	Study Duration	10–30min (1)[dur2-12], 1–2hr (1)[dur4-12], 2–4hr (1)[dur5-12]
	Activity	Gaming (2)[act8-12], Gesture (1)[act9-12], Holding Objects (4)[act10-12], Moving Objects (2)[act12-12], Navigational Task (1)[act14-12], Others (7)[act18-12], No Task (1)[act19-12], Sitting (1)[act27-12], VR Non-Fictional (2)[act33-12], Walking (2)[act34-12]
Training (n = 17)	Ethics	Yes (7)[ethY13]; No (10)[ethN13]
	Study Type	Qualitative (0)[st1-10]; Quantitative (11)[st2-10] Both (5)[st3-10]; Not Applicable (0)[st4-10]

(continued on next page)

Application Area	Characteristic	Summary (Count)
	Methodology	Experimental (3)[meth4-13], Feasibility (1)[meth5-13], Not Reported (5)[meth8-13], Others (3)[meth9-13], Pilot (3)[meth10-13], Preliminary Study (1)[meth11-13], Survey (1)[meth13-13]
	Study Design	Between Participants (2)[sd1-13], Within Participants (11)[sd2-13], Not Sure (0)[sd3-13], Others (0)[sd4-13], Not Reported (4)[sd5-13]
	Study Duration	30–60min (2)[dur3-13], 1–2hr (2)[dur4-13]

(continued on next page)

Application Area	Characteristic	Summary (Count)
	Activity	Artistity (1)[act1-13], Aseembly (1)[act2-13], Holding Objects (1)[act10-13], Medical Procedures (4)[act11-13], Moving Objects (2)[act12-13], Object Recognition (1)[act17-13], Others (6)[act18-13], Pattern Recognition (2)[act20-13], Product Evaluation (1)[act22-13], Sitting (2)[act27-13], Surgical Training (2)[act30-13], VR Ficitional (1)[act32-13], VR Non-Fictional (3)[act33-13], Walking (1)[act34-13], Writing (1)[act36-13]

Table D.4: The table provides an overview of device-specific reporting across the top 12 application areas identified in our dataset. It includes details on device origin, cost, technology used, and body laterality. Superscripts refer to variable codes defined in Appendix in Table D.7; each code maps to the full list of paper identifiers contributing to the corresponding value.

Application Areas	Reporting Category	Details(paper count)

Virtual Reality (n = 157)	Device Origin	Commercial (55)[do1-1]; Custom (90)[do2-1]; Previously Reported Device (7)[do3-1]; Props (17)[do4-1]; Others (4)[do5-1]; Not Reported (6)[do6-1];
	Device Cost	Low Cost (10)[cd1-1]; ¡$100 (1)[cd2-1]; ¡$50 (1)[cd3-1]; ¡$500 (2)[cd4-1]; Very Expensive (1)[cd6-1]; Not Reported (146)[cd7-1];
	Technology Used	LRA (13)[tu1-1]; ERM (2)[tu2-1]; Wideband (1)[tu3-1]; Piezoelectric (2)[tu4-1]; Electrical Simulation (5)[tu5-1]; Exoskeleton (4)[tu6-1]; Force Feedback System (12)[tu7-1]; Mid-air / Ultrasound (9)[tu10-1]; Motor and Actuator (56)[tu11-1]; Others (95)[tu12-1]; Pneumatic (4)[tu13-1]; Propellers (2)[tu15-1]; Robotic Arm (3)[tu16-1]; Robots (3)[tu17-1]; Surface Haptics (3)[tu19-1]; Thermal (6)[tu20-1]; Wearable Technology (22)[tu21-1];

	Body Laterality	bottom (1)[bl1-1]; dominant (31)[bl2-1]; left (18)[bl3-1]; non-dominant (3)[bl4-1]; not applicable (24)[bl5-1]; other (8)[bl6-1]; right (31)[bl7-1]; top (1)[bl8-1]; not reported (67)[bl9-1];
Wearables (n = 59)	Device Origin	Commercial (2)[do1-2]; Custom (56)[do2-2]; Previously Reported Device (3)[do3-2]; Not Reported (1)[do6-2];
	Device Cost	Low Cost (5)[cd1-2]; ¡$50 (1)[cd3-2]; ¡$500 (1)[cd4-2]; Not Reported (54)[cd7-2];
	Technology Used	LRA (6)[tu1-2]; ERM (1)[tu2-2]; Piezoelectric (1)[tu4-2]; Exoskeleton (3)[tu6-2]; Force Feedback System (2)[tu7-2]; Mid-air / Ultrasound (3)[tu10-2]; Motor and Actuator (39)[tu11-2]; Others (34)[tu12-2]; Pneumatic (2)[tu13-2]; SMAs (1)[tu18-2]; Surface Haptics (1)[tu19-2]; Thermal (2)[tu20-2]; Wearable Technology (27)[tu21-2];

	Body Laterality	bottom (4)[bl1-2]; dominant (9)[bl2-2]; left (12)[bl3-2]; non-dominant (2)[bl4-2]; not applicable (4)[bl5-2]; other (4)[bl6-2]; right (8)[bl7-2]; top (3)[bl8-2]; not reported (27)[bl9-2]
Robotics (n = 52)	Device Origin	Commercial (17)[do1-3]; Custom (34)[do2-3]; Previously Reported Device (7)[do3-3]; Props (1)[do4-3]; Others (2)[do5-3]; Not Reported (1)[do6-3];
	Device Cost	Low Cost (2)[cd1-3]; ¡$500 (1)[cd4-3]; Not Reported (51)[cd7-3];
	Technology Used	LRA (1)[tu1-3]; Exoskeleton (6)[tu6-3]; Force Feedback System (7)[tu7-3]; Mid-air / Ultrasound (2)[tu10-3]; Motor and Actuator (32)[tu11-3]; Others (26)[tu12-3]; Pneumatic (3)[tu13-3]; Propellers (3)[tu15-3]; Robotic Arm (7)[tu16-3]; Robots (1)[tu17-3]; SMAs (1)[tu18-3]; Wearable Technology (9)[tu21-3];

	Body Laterality	dominant (7)[bl2-3]; left (4)[bl3-3]; non-dominant (2)[bl4-3]; not applicable (5)[bl5-3]; other (5)[bl6-3]; right (10)[bl7-3]; top (2)[bl8-3]; not reported (23)[bl9-3]
Accessibility (n = 40)	Device Origin	Commercial (8)[do1-4]; Custom (31)[do2-4]; Previously Reported Device (6)[do3-4]; Others (1)[do5-4]; Not Reported (1)[do6-4];
	Device Cost	Low Cost (5)[cd1-4]; ¡$100 (1)[cd2-4]; ¡$3000 (1)[cd5-4]; ¡$500 (2)[cd4-4]; Not Reported (33)[cd7-4];
	Technology Used	LRA (3)[tu1-4]; ERM (1)[tu2-4]; Piezoelectric (2)[tu4-4]; Exoskeleton (3)[tu6-4]; Force Feedback System (2)[tu7-4]; Motor and Actuator (19)[tu11-4]; Others (22)[tu12-4]; Wearable Technology (5)[tu21-4];
	Body Laterality	bottom (2)[bl1-4]; dominant (5)[bl2-4]; left (7)[bl3-4]; not applicable (11)[bl5-4]; other (2)[bl6-4]; right (6)[bl7-4]; not reported (18)[bl9-4]

Teleoperation (n = 40)	Device Origin	Commercial (12)[do1-5]; Custom (25)[do2-5]; Previously Reported Device (4)[do3-5]; Others (1)[do5-5]; Not Reported (2)[do6-5];
	Device Cost	Low Cost (2)[cd1-5]; Not Reported (38)[cd7-5];
	Technology Used	LRA (1)[tu1-5]; Exoskeleton (3)[tu6-5]; Force Feedback System (9)[tu7-5]; Motor and Actuator (24)[tu11-5]; Others (20)[tu12-5]; Pneumatic (2)[tu13-5]; Propellers (3)[tu15-5]; Robotic Arm (5)[tu16-5]; SMAs (1)[tu18-5]; Wearable Technology (10)[tu21-5];
	Body Laterality	bottom (1)[bl1-5]; dominant (8)[bl2-5]; left (2)[bl3-5]; not applicable (5)[bl5-5]; other (2)[bl6-5]; right (6)[bl7-5]; top (1)[bl8-5]; not reported (17)[bl9-5]
Medical (n = 30)	Device Origin	Commercial (10)[do1-6]; Custom (18)[do2-6]; Previously Reported Device (5)[do3-6]; Props (2)[do4-6]; Not Reported (1)[do6-6];

	Device Cost	Low Cost (2)[cd1-6]; ¡$500 (1)[cd4-6]; Very Expensive (1)[cd6-6]; Not Reported (26)[cd7-6];
	Technology Used	LRA (4)[tu1-6]; ERM (1)[tu2-6]; Exoskeleton (2)[tu6-6]; Force Feedback System (6)[tu7-6]; Magnetic Levitation (1)[tu8-6]; MR Fluid System (1)[tu9-6]; Mid-air / Ultrasound (2)[tu10-6]; Motor and Actuator (12)[tu11-6]; Others (16)[tu12-6]; Pneumatic (1)[tu13-6]; Pressure Sensitive Material (1)[tu14-6]; Robotic Arm (2)[tu16-6]; Wearable Technology (6)[tu21-6];
	Body Laterality	bottom (2)[bl1-6]; dominant (4)[bl2-6]; left (3)[bl3-6]; non-dominant (1)[bl4-6]; not applicable (4)[bl5-6]; right (3)[bl7-6]; top (1)[bl8-6]; not reported (16)[bl9-6]
Augmented Reality (n = 26)	Device Origin	Commercial (9)[do1-7]; Custom (16)[do2-7]; Previously Reported Device (1)[do3-7]; Props (1)[do4-7]; Others (1)[do5-7]; Not Reported (1)[do6-7];

	Device Cost	Low Cost (3)[cd1-7]; ¡$50 (1)[cd3-7]; Not Reported (24)[cd7-7];
	Technology Used	LRA (5)[tu1-7]; Piezoelectric (1)[tu4-7]; Electrical Simulation (1)[tu5-7]; Exoskeleton (1)[tu6-7]; Force Feedback System (1)[tu7-7]; Mid-air / Ultrasound (1)[tu10-7]; Motor and Actuator (10)[tu11-7]; Others (14)[tu12-7]; Propellers (1)[tu15-7]; Robotic Arm (1)[tu16-7]; SMAs (1)[tu18-7]; Wearable Technology (5)[tu21-7];
	Body Laterality	dominant (6)[bl2-7]; left (4)[bl3-7]; non-dominant (2)[bl4-7]; not applicable (2)[bl5-7]; other (1)[bl6-7]; right (8)[bl7-7]; not reported (12)[bl9-7]
Virtual Environment (n = 25)	Device Origin	Commercial (11)[do1-8]; Custom (16)[do2-8]; Previously Reported Device (2)[do3-8]; Others (1)[do5-8]; Not Reported (2);
	Device Cost	¡$500 (1)[cd4-8]; Not Reported (25)[cd7-8];

	Technology Used	LRA (2)[tu1-8]; Force Feedback System (2)[tu7-8]; Magnetic Levitation (1)[tu8-8]; MR Fluid System (1)[tu9-8]; Mid-air / Ultrasound (3)[tu10-8]; Motor and Actuator (7)[tu11-8]; Others (16)[tu12-8]; Pneumatic (1)[tu13-8]; Propellers (1)[tu15-8]; Robotic Arm (1)[tu16-8]; SMAs (1)[tu18-8]; Surface Haptics (1)[tu19-8]; Wearable Technology (1)[tu21-8];
	Body Laterality	dominant (5)[bl2-8]; left (5)[bl3-8]; not applicable (6)[bl5-8]; other (1)[bl6-8]; right (6)[bl7-8]; not reported (10)[bl9-8]
Gaming (n = 25)	Device Origin	Commercial (8)[do1-9]; Custom (19)[do2-9]; Previously Reported Device (0)[do3-9]; Props (2)[do4-9]; Not Reported (0);
	Device Cost	Low Cost (3)[cd1-9]; ¡$100 (1)[cd2-9]; ¡$500 (1)[cd4-9]; Not Reported (20)[cd7-9];

	Technology Used	LRA (2)[tu1-9]; ERM (1)[tu2-9]; Force Feedback System (1)[tu7-9]; Mid-air / Ultrasound (1)[tu10-9]; Motor and Actuator (11)[tu11-9]; Others (15)[tu12-9]; Pneumatic (1)[tu13-9]; Pressure Sensitive Material (1)[tu14-9]; Surface Haptics (2)[tu19-9]; Wearable Technology (6)[tu21-9];
	Body Laterality	bottom (1)[bl1-9]; dominant (3)[bl2-9]; left (3)[bl3-9]; non-dominant (1)[bl4-9]; not applicable (4)[bl5-9]; right (2)[bl7-9]; top (1)[bl8-9]; not reported (13)[bl9-9]
Affective Computing (n = 17)	Device Origin	Commercial (5)[do1-10]; Custom (14)[do2-10]; Previously Reported Device (1)[do3-10]; Others (1)[do5-10]; Not Reported (0);
	Device Cost	Not Reported (20)[cd7-10];

	Technology Used	LRA (2)[tu1-10]; ERM (1)[tu2-10]; Force Feedback System (1)[tu7-10]; Motor and Actuator (10)[tu11-10]; Others (6)[tu12-10]; Pneumatic (1)[tu13-10]; SMAs (1)[tu18-10]; Surface Haptics (1)[tu19-10]; Wearable Technology (2)[tu21-10];
	Body Laterality	dominant (5)[bl2-10]; left (1)[bl3-10]; non-dominant (2)[bl4-10]; not applicable (3)[bl5-10]; other (5)[bl6-10]; right (1)[bl7-10]; top (2)[bl8-10]; not reported (1)[bl9-10]
Rehabilitation (n = 17)	Device Origin	Commercial (2)[do1-11]; Custom (11)[do2-11]; Previously Reported Device (5)[do3-11]; Not Reported (1)[do6-11];
	Device Cost	Low Cost (1)[cd1-11]; Not Reported (16)[cd7-11];

	Technology Used	LRA (1)[tu1-11]; ERM (1)[tu2-11]; Exoskeleton (3)[tu6-11]; Force Feedback System (3)[tu7-11]; Motor and Actuator (9)[tu11-11]; Others (4)[tu12-11]; Robotic Arm (2)[tu16-11]; Wearable Technology (4)[tu21-11];
	Body Laterality	dominant (2)[bl2-11]; left (3)[bl3-11]; non-dominant (1)[bl4-11]; not applicable (5)[bl5-11]; other (3)[bl6-11]; right (3)[bl7-11]; top (1)[bl8-11]; not reported (3)[bl9-11]
Training (n = 16)	Device Origin	Commercial (10)[do1-12]; Custom (8)[do2-12]; Previously Reported Device (1)[do3-12]; Props (1)[do4-12]; Others (1)[do5-12]; Not Reported (0);
	Device Cost	Low Cost (1)[cd1-12]; Not Reported (16)[cd7-12];
	Technology Used	Force Feedback System (3)[tu7-12]; Motor and Actuator (9)[tu11-12]; Others (10)[tu12-12]; Surface Haptics (1)[tu19-12]; Wearable Technology (3)[tu21-12];

Body Laterality	dominant (2)[bl2-12]; left (1)[bl3-12]; not applicable (2)[bl5-12]; other (1)[bl6-12]; right (3)[bl7-12]; not reported (9)[bl9-12]

D.0.2 Variable Codes and Associated Paper Identifiers

Table D.5: The table lists the variable codes used as superscripts in Table D.3, which summarizes study methodologies across the top 12 application areas in haptic research. Table D.3 values for ethics approval, study type, methodology, study design, duration, and user activity. Each superscript code in Table D.3 corresponds to an entry here, where the full list of contributing paper identifiers is provided.

Code	**Paper IDs**
ethY1	[538, 417, 233, 299, 162, 605, 563, 339, 265, 307, 565, 59, 128, 577, 159, 53, 607, 48, 200, 429, 585, 606, 560, 533, 526, 181, 134, 196, 405, 79, 582, 227, 489, 270, 158, 45, 273, 394, 44, 420, 558, 295, 303, 257, 621, 266, 54, 377, 327, 131, 576, 533, 30]
ethY3	[157, 440, 262, 311, 369, 95, 337, 48, 400, 597, 178, 272, 179, 445, 542, 227, 401, 156, 486, 23, 420, 353, 305, 278, 298, 413, 598, 327, 345, 100]

Code	Paper IDs
ethY4	[363, 368, 95, 33, 571, 507, 487, 617, 85, 9, 61, 510, 370, 559, 433, 287, 552, 459, 272, 227, 158, 486, 92, 394, 398, 93, 487, 576]
ethY5	[268, 614, 571, 263, 507, 150, 504, 99, 397, 539, 395, 445, 35, 275, 282, 278, 298, 377, 30]
ethY6	[86, 440, 571, 343, 510, 344, 559, 610, 296, 433, 560, 114, 438, 270, 269, 92, 394, 44, 23, 420, 558, 303]
ethY7	[273]
ethY8	[611, 277, 249, 53, 533, 405, 227, 156, 420, 54, 533]
ethY9	[475, 565, 59, 315, 450, 398]
ethY10	[369, 263, 200, 12, 582, 266, 509, 327]
ethY11	[252, 617, 177, 108, 61, 510, 370, 422, 594]
ethY12	[21, 267, 311, 605, 140, 316, 10, 599, 159, 456, 315, 405, 227, 282, 257]
ethY13	[149, 565, 241, 48, 560, 79, 327]

Code	Paper IDs
ethN1	[553, 40, 525, 49, 380, 548, 623, 479, 187, 463, 195, 42, 41, 154, 110, 16, 399, 94, 119, 231, 376, 432, 608, 385, 437, 251, 203, 615, 214, 183, 189, 271, 104, 88, 236, 254, 573, 14, 622, 132, 202, 193, 465, 365, 537, 366, 326, 239, 336, 109, 142, 453, 612, 625, 544, 626, 56, 172, 529, 124, 447, 335, 18, 225, 234, 483, 168, 439, 591, 285, 230, 448, 588, 511, 39, 210, 505, 464, 253, 129, 388, 390, 112, 274, 430, 423, 256, 194, 593, 300, 564, 320, 596, 78, 562, 211, 528, 549, 240, 465, 561, 546, 130, 209, 235, 228]
ethN3	[155, 380, 414, 387, 604, 357, 58, 62, 412, 203, 104, 313, 544, 454, 220, 172, 502, 419, 18, 342, 136, 285, 372, 106, 291, 390, 586, 97, 497, 604]
ethN4	[553, 498, 323, 191, 52, 609, 532, 166, 107, 425, 312, 104, 478, 480, 454, 220, 238, 476, 290, 372, 106, 122, 69, 274, 378, 564]
ethN5	[371, 24, 584, 180, 145, 244, 604, 376, 27, 530, 375, 512, 545, 536, 36, 543, 483, 276, 604, 126, 442, 602]
ethN6	[498, 548, 89, 323, 191, 314, 107, 104, 453, 544, 19, 11, 105, 117, 122, 69, 490, 341]
ethN7	[479, 286, 22, 52, 214, 239, 190, 142, 529, 541, 122, 497]

Code	Paper IDs
ethN8	[554, 141, 414, 518, 412, 183, 365, 313, 612, 419, 285, 511, 372, 129, 430, 130]
ethN9	[553, 145, 399, 592, 375, 615, 271, 88, 236, 254, 544, 56, 172, 483, 541, 388, 274, 458, 418]
ethN10	[414, 195, 42, 387, 110, 16, 183, 573, 622, 109, 453, 355, 447, 230, 503, 546, 192]
ethN11	[389, 421, 185, 166, 437, 425, 478, 402, 220, 297]
ethN12	[312, 234]
ethN13	[141, 479, 195, 618, 317, 101, 214, 176, 56, 546]
st1	[538, 233, 119, 376, 437, 254, 537]
st1-3	[369, 387]
st1-4	[191, 52, 370]
st1-5	[376, 99]
st1-6	[191]
st1-7	[52]
st1-8	[554]
st1-9	[592, 254]
st1-10	[369, 387, 503]

Code	Paper IDs
st1-11	[370, 437, 594]
st2	[417, 299, 40, 162, 380, 563, 195, 42, 307, 154, 399, 565, 94, 59, 608, 53, 203, 189, 271, 48, 104, 200, 88, 236, 573, 622, 429, 585, 132, 606, 193, 560, 465, 533, 365, 366, 239, 336, 134, 109, 142, 453, 196, 405, 625, 544, 626, 56, 79, 582, 227, 172, 529, 124, 225, 44, 388, 295, 303, 274, 430, 621, 266, 54, 423, 194, 593, 564, 465, 533, 130, 209, 235]
st2-3	[157, 155, 440, 380, 262, 311, 95, 604, 58, 62, 412, 203, 337, 48, 104, 597, 178, 272, 179, 544, 445, 542, 227, 172, 106, 291, 23, 586, 305, 278, 298, 97, 497, 604, 345, 100]
st2-4	[498, 95, 323, 33, 571, 507, 85, 312, 104, 559, 480, 287, 552, 272, 227, 106, 122, 69, 274, 398, 378, 93, 564]
st2-5	[614, 180, 571, 263, 507, 145, 244, 604, 397, 395, 375, 445, 35, 36, 282, 278, 298, 276, 604, 602]
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st3-13	[141, 479, 214, 327, 546]
st4	[605, 187, 231]
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dru3-4	[287, 220, 274, 564]
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dru4-3	[369, 95, 203, 401, 502, 342, 136, 420, 390, 598, 327, 497, 345]
dru4-4	[553, 95, 61, 510, 459, 378, 93]
dru4-5	[539, 512, 543, 276, 126]
dru4-6	[510, 420, 117]
dru4-7	[8, 87, 529, 497]
dru4-8	[554, 518, 511, 420, 54]
dru4-9	[553, 458]
dru4-10	[369, 582, 327, 546]
dru4-11	[61, 510]
dru4-12	[599]
dru4-13	[327, 546]
dru5	[533, 158, 388, 211]
dru5-3	[419]
dru5-4	[158]

Code	Paper IDs
dru5-5	[263, 504]
dru5-8	[533, 419]
dru5-9	[315, 388]
dru5-10	[263]
dru5-11	[402]
dru5-12	[315]
dru6-3	[445]
dru6-4	[445, 275]
dru6-10	[177, 594]
dru7	[377]
dru7-3	[387, 62, 97]
dru7-4	[571]
dru7-5	[268, 571, 377]
dru7-6	[571]
dru7-7	[571, 362, 595]
dru7-8	[475]
dru7-9	[387]

Table D.6: This table lists the variable codes used as superscripts in Table D.2, which summarizes participant characteristics across the top 12 application areas in haptic research. These include values for target population, age reporting, gender reporting, and sample size. Each superscript code in Table D.2 corresponds to an entry here, where the full list of contributing paper identifiers is provided.

Code	**Paper IDs**
tp1-1	[565]
tp1-2	[497]
tp1-6	[362, 497]
tp1-8	[565]
tp1-12	[565]
tp2-1	[385, 437, 251]
tp2-2	[357, 313, 97]
tp2-3	[191, 61, 609]
tp2-4	[530]
tp2-5	[191, 343, 510]
tp2-6	[286, 22, 87]
tp2-7	[611, 277, 249]
tp2-8	[592]
tp2-10	[177, 108, 61]
tp2-11	[159, 405]

Code	Paper IDs
tp2-12	[101]
tp3-2	[311]
tp3-11	[311]
tp4-1	[376, 483, 30]
tp4-2	[278]
tp4-4	[371, 263, 150]
tp4-8	[483]
tp4-9	[263]
tp5-1	[376, 377]
tp5-4	[376, 375, 377]
tp5-8	[375]
tp6-1	[112, 430]
tp6-2	[278]
tp6-3	[92]
tp6-4	[584, 278]
tp6-5	[92]
tp6-7	[430]
tp6-10	[297]

Code	Paper IDs
tp7-1	[538, 553, 417, 299, 40, 525, 49, 380, 623, 605, 265, 195, 41, 154, 110, 16, 119, 59, 231, 203, 183, 189, 48, 104, 88, 236, 254, 14, 622, 429, 585, 132, 202, 606, 193, 560, 533, 365, 537, 326, 239, 134, 109, 142, 453, 612, 544, 56, 172, 124, 447, 270, 335, 18, 234, 591, 285, 448, 588, 511, 505, 464, 129, 394, 420, 558, 390, 430, 423, 256, 194, 327, 596, 576, 240, 561, 546, 209, 235, 228]
tp7-2	[157, 155, 440, 380, 414, 95, 387, 604, 58, 412, 203, 48, 104, 400, 597, 272, 179, 544, 454, 220, 172, 401, 502, 419, 18, 156, 342, 285, 372, 106, 23, 420, 390, 353, 586, 305, 298, 413, 327, 100]
tp7-3	[553, 498, 368, 95, 532, 312, 104, 559, 478, 480, 433, 552, 272, 454, 220, 290, 372, 394, 106, 398, 576]
tp7-4	[604, 27, 35, 36, 298, 276, 602]
tp7-5	[498, 86, 440, 104, 559, 610, 433, 560, 453, 544, 19, 270, 11, 105, 269, 394, 23, 420, 558]
tp7-6	[149, 8, 559, 239, 142, 156, 450, 541, 298]
tp7-7	[414, 412, 183, 533, 365, 612, 419, 156, 285, 511, 372, 129, 420, 430]

Code	Paper IDs
tp7-8	[553, 475, 59, 88, 236, 254, 544, 56, 172, 450, 541, 398, 418]
tp7-9	[414, 195, 387, 110, 16, 183, 622, 109, 453, 12, 355, 447, 327, 546]
tp7-10	[252, 478, 402, 220]
tp7-11	[21, 605, 140, 312, 456, 234]
tp7-12	[149, 195, 48, 560, 56, 327, 546]
tp8-1	[479]
tp8-6	[479]
tp8-12	[479]
tp9-1	[463, 489, 327]
tp9-2	[327]
tp9-9	[327]
tp9-12	[327]
tp10-1	[233, 479, 187, 463, 265, 307, 94, 432, 615, 214, 336, 79, 582, 230, 273, 390, 257, 274, 621, 266, 54, 320, 78, 549, 30]
tp10-2	[369, 445, 390]

Code	Paper IDs
tp10-3	[363, 274, 93]
tp10-4	[268, 24, 445, 536, 30]
tp10-5	[490]
tp10-6	[352, 479, 214, 273]
tp10-7	[554, 518, 54]
tp10-8	[615, 274]
tp10-9	[369, 582, 230, 266]
tp10-10	[185, 297]
tp10-11	[257]
tp10-12	[479, 214, 79]
tp12-1	[265, 42, 16, 399, 608, 79, 582, 274, 266, 54, 320, 528, 549]
tp12-2	[313, 445]
tp12-3	[363, 33, 274]
tp12-4	[395, 375, 445, 536]
tp12-5	[314]
tp12-6	[352]
tp12-7	[313, 54]
tp12-8	[399, 375, 274]

Code	Paper IDs
tp12-9	[42, 16, 582, 266]
tp12-10	[421, 185]
tp12-11	[10]
tp12-12	[241, 79]
tp13-3	[571]
tp13-4	[571, 145]
tp13-5	[571]
tp13-6	[571]
tp13-6	[571]
tp13-8	[145]
tp14-4	[614, 150]
tp14-6	[595]
tp14-7	[141]
tp14-12	[141]
tp15-4	[268, 244]
tp16-4	[504]
tp17-6	[286]
tp18-1	[168]

Code	Paper IDs
tp18-9	[503]
tp19-12	[317]
tp20-2	[97]
ar1-1	[538, 417, 233, 525, 339, 154, 565, 53, 88, 622, 429, 533, 181, 453, 612, 625, 626, 56, 172, 447, 18, 225, 168, 285, 230, 511, 39, 464, 129, 44, 303, 257, 564, 549, 533, 130, 228]
ar1-2	[157, 155, 311, 414, 369, 95, 604, 454, 172, 502, 18, 156, 285, 291, 353, 97, 497, 604, 100]
ar1-3	[498, 368, 95, 33, 425, 312, 459, 454, 290, 69, 564]
ar1-4	[263, 145, 604, 99, 395, 282, 604]
ar1-5	[498, 296, 114, 453, 11, 44, 69, 303]
ar1-6	[352, 156, 497]
ar1-7	[414, 53, 533, 612, 156, 285, 511, 129, 533, 130]
ar1-8	[145, 565, 88, 56, 172, 418]
ar1-9	[414, 369, 263, 622, 453, 12, 355, 447, 230, 503]
ar1-10	[108, 421, 425, 402, 422]
ar1-11	[21, 311, 316, 312, 282, 257]

Code	Paper IDs
ar1-12	[565, 317, 56]
ar2-1	[553, 299, 49, 162, 548, 623, 479, 563, 463, 195, 42, 41, 110, 94, 119, 376, 128, 432, 608, 385, 437, 251, 159, 607, 203, 615, 214, 189, 200, 236, 254, 14, 132, 202, 606, 193, 465, 326, 336, 134, 582, 439, 448, 588, 210, 420, 388, 295, 390, 112, 274, 266, 423, 256, 377, 131, 593, 300, 320, 596, 211, 576, 240, 465, 546, 209, 235]
ar2-2	[440, 412, 203, 337, 178, 313, 179, 445, 419, 342, 136, 420, 390, 598, 345]
ar2-3	[553, 363, 487, 191, 52, 61, 433, 476, 274, 378, 93, 487, 576]
ar2-4	[371, 268, 614, 584, 244, 376, 397, 530, 539, 375, 445, 377, 276, 126]
ar2-5	[440, 548, 191, 433, 420]
ar2-6	[479, 52, 159, 214, 595]
ar2-7	[554, 141, 611, 412, 313, 419, 420]
ar2-8	[553, 592, 375, 615, 236, 254, 388, 274, 458]
ar2-9	[195, 42, 110, 200, 582, 266, 546]
ar2-10	[252, 177, 61, 437, 297]

Code	Paper IDs
ar2-11	[267, 159]
ar2-12	[141, 479, 195, 214, 546]
ar3-1	[187, 265, 399, 96, 577, 271, 239, 142, 196, 529, 124, 489, 270, 158, 505, 253, 394, 430, 54]
ar3-2	[262, 357, 58, 597, 272, 486, 586]
ar3-3	[617, 9, 532, 166, 370, 107, 552, 272, 238, 158, 486, 92, 394, 122, 398]
ar3-4	[24, 27, 512, 36, 442, 602]
ar3-5	[89, 314, 343, 107, 344, 19, 270, 105, 269, 92, 394, 122]
ar3-6	[149, 286, 239, 142, 601, 529, 486, 122]
ar3-7	[96, 430, 54]
ar3-8	[399, 96, 271, 398]
ar3-10	[125, 617, 389, 166, 370]
ar3-11	[140, 10, 456]
ar3-12	[149, 241, 101, 176]
ar4-1	[40, 380, 605, 307, 16, 59, 231, 183, 48, 104, 573, 585, 560, 365, 537, 526, 366, 109, 405, 544, 79, 227, 335, 234, 483, 45, 591, 273, 558, 621, 194, 327, 78, 562, 528, 561, 30]

Code	Paper IDs
ar4-2	[380, 387, 62, 48, 104, 400, 544, 542, 227, 220, 401, 372, 106, 23, 305, 278, 298, 413, 327]
ar4-3	[323, 571, 507, 85, 609, 510, 104, 559, 478, 480, 287, 227, 220, 372, 106]
ar4-4	[180, 571, 507, 150, 504, 545, 35, 275, 536, 543, 483, 278, 298, 30]
ar4-5	[86, 323, 571, 510, 104, 559, 610, 560, 438, 544, 23, 558, 117, 490, 341]
ar4-6	[571, 507, 362, 8, 85, 22, 87, 559, 190, 438, 450, 273, 541, 298]
ar4-7	[518, 277, 249, 183, 365, 405, 227, 372]
ar4-8	[475, 59, 315, 544, 483, 450, 541]
ar4-9	[387, 16, 183, 573, 109, 509, 327, 192]
ar4-10	[510, 185, 478, 220, 594]
ar4-11	[605, 599, 315, 405, 227, 234]
ar4-12	[618, 48, 560, 79, 327]

Code	Paper IDs
gr1-1	[538, 553, 417, 233, 299, 40, 49, 162, 548, 623, 479, 605, 187, 563, 339, 463, 265, 195, 42, 307, 41, 154, 110, 16, 565, 94, 119, 59, 231, 376, 128, 432, 608, 385, 251, 577, 159, 53, 607, 203, 615, 214, 189, 48, 104, 236, 254, 573, 14, 622, 585, 132, 606, 193, 560, 465, 533, 365, 537, 366, 326, 181, 336, 109, 142, 453, 405, 625, 544, 626, 56, 582, 172, 489, 270, 335, 158, 225, 234, 168, 45, 439, 591, 230, 448, 588, 39, 210, 505, 273, 129, 394, 44, 295, 390, 303, 257, 112, 274, 430, 621, 266, 54, 423, 256, 377, 194, 327, 131, 564, 320, 596, 562, 211, 528, 549, 465, 561, 130, 209, 235, 30]
gr1-2	[157, 311, 414, 369, 95, 387, 604, 357, 58, 62, 412, 203, 48, 104, 400, 597, 178, 313, 179, 544, 454, 445, 542, 220, 172, 401, 419, 342, 486, 372, 106, 23, 390, 353, 305, 278, 298, 413, 598, 327, 604]
gr1-3	[553, 498, 363, 368, 95, 323, 33, 571, 507, 487, 85, 510, 425, 104, 559, 478, 480, 433, 287, 552, 459, 454, 220, 158, 476, 486, 290, 92, 372, 394, 106, 122, 69, 274, 378, 487, 564]

Code	Paper IDs
gr1-4	[371, 268, 614, 24, 584, 571, 263, 507, 145, 244, 604, 504, 376, 99, 397, 539, 395, 375, 545, 445, 35, 536, 282, 278, 298, 377, 276, 604, 126, 602, 30]
gr1-5	[498, 548, 323, 571, 510, 104, 559, 296, 433, 560, 453, 438, 544, 19, 270, 105, 269, 92, 394, 44, 23, 117, 122, 69, 490, 341, 303]
gr1-6	[479, 571, 507, 8, 85, 22, 87, 159, 214, 559, 142, 438, 486, 450, 273, 541, 122, 298, 595]
gr1-7	[554, 414, 518, 611, 277, 53, 412, 533, 365, 313, 405, 419, 372, 129, 430, 54, 130]
gr1-8	[553, 475, 145, 565, 59, 592, 375, 615, 236, 254, 544, 56, 172, 450, 541, 274, 458, 418]
gr1-9	[414, 369, 263, 195, 42, 387, 110, 16, 573, 622, 109, 453, 582, 230, 266, 509, 327, 503]
gr1-10	[252, 177, 108, 510, 425, 478, 402, 220, 297, 594]
gr1-11	[267, 311, 605, 140, 316, 159, 405, 234, 282, 257]
gr1-12	[479, 195, 565, 618, 317, 214, 48, 560, 56, 327]

Code	Paper IDs
gr2-1	[538, 553, 417, 233, 299, 40, 525, 49, 162, 548, 479, 605, 187, 563, 339, 463, 265, 195, 42, 307, 41, 154, 110, 16, 565, 94, 119, 59, 231, 376, 128, 608, 385, 251, 577, 159, 53, 607, 203, 615, 214, 189, 48, 104, 200, 236, 254, 573, 14, 622, 429, 585, 202, 606, 193, 560, 465, 365, 537, 526, 366, 326, 181, 336, 134, 109, 142, 453, 625, 544, 626, 56, 582, 227, 172, 489, 447, 270, 335, 158, 483, 439, 591, 285, 230, 448, 588, 511, 39, 210, 505, 464, 253, 273, 129, 394, 44, 388, 295, 390, 112, 274, 430, 621, 266, 54, 423, 256, 377, 194, 327, 131, 564, 320, 596, 562, 211, 528, 549, 576, 240, 465, 561, 546, 130, 209, 235, 30, 228]
gr2-2	[157, 155, 311, 414, 369, 95, 387, 604, 357, 58, 62, 412, 203, 48, 104, 400, 597, 178, 313, 179, 544, 454, 445, 542, 227, 220, 172, 401, 502, 419, 156, 342, 136, 285, 372, 106, 23, 390, 353, 305, 278, 298, 413, 97, 598, 327, 604, 345, 100]
gr2-3	[553, 498, 363, 368, 95, 323, 507, 85, 52, 510, 425, 104, 559, 478, 480, 433, 287, 459, 454, 227, 220, 158, 476, 92, 372, 394, 106, 122, 69, 274, 378, 93, 564, 576]

Code	Paper IDs
gr2-4	[268, 614, 24, 584, 263, 507, 244, 604, 504, 376, 99, 397, 539, 395, 375, 545, 445, 35, 536, 483, 282, 278, 298, 377, 276, 604, 126, 602, 30]
gr2-5	[498, 548, 323, 510, 104, 559, 610, 433, 560, 114, 453, 438, 544, 19, 270, 105, 269, 92, 394, 44, 23, 117, 122, 69, 490, 341]
gr2-6	[479, 507, 85, 22, 87, 52, 159, 214, 559, 142, 438, 156, 450, 273, 541, 122, 298, 595]
gr2-7	[554, 414, 518, 611, 277, 53, 412, 365, 313, 227, 419, 156, 285, 511, 372, 129, 430, 54, 130]
gr2-8	[553, 475, 565, 59, 592, 375, 615, 236, 254, 544, 56, 172, 483, 450, 541, 388, 274, 458, 418]
gr2-9	[414, 369, 263, 195, 42, 387, 110, 16, 200, 573, 622, 109, 453, 12, 582, 355, 447, 230, 266, 509, 327, 503, 546, 192]
gr2-10	[252, 177, 108, 510, 425, 478, 402, 220, 297, 422, 594]
gr2-11	[267, 311, 605, 316, 159, 227, 282]
gr2-12	[479, 195, 565, 618, 317, 214, 48, 560, 56, 327, 546]
gr3-1	[187, 54]
gr3-2	[97, 345]

Code	Paper IDs
gr3-3	[368]
gr3-4	[602]
gr3-7	[54]
gr3-9	[509]
gr3-10	[422]
gr4-1	[380, 399, 96, 437, 183, 271, 88, 239, 612, 196, 79, 529, 124, 18, 420, 558, 593, 300, 78, 533]
gr4-2	[440, 380, 262, 337, 272, 18, 291, 420, 586, 497]
gr4-3	[617, 191, 9, 61, 609, 532, 166, 370, 107, 312, 272, 238, 398]
gr4-4	[180, 150, 27, 530, 512, 275, 36, 543, 442]
gr4-5	[86, 440, 89, 191, 314, 343, 107, 344, 11, 420, 558]
gr4-6	[352, 149, 362, 286, 239, 190, 601, 529, 497]
gr4-7	[141, 96, 249, 183, 612, 420, 533]
gr4-8	[399, 96, 271, 88, 315, 398]
gr4-9	[183]
gr4-10	[125, 617, 389, 421, 61, 185, 166, 370, 437]
gr4-11	[21, 10, 599, 312, 456, 315]

Code	Paper IDs
gr4-12	[141, 149, 241, 101, 176, 79]
ss1-1	[553, 525, 623, 605, 339, 16, 565, 48, 104, 14, 429, 585, 132, 533, 537, 326, 405, 56, 227, 447, 225, 234, 483, 45, 439, 285, 511, 464, 253, 303, 257, 256, 131, 576, 240, 546, 235, 30, 228]
ss1-2	[155, 387, 357, 58, 48, 104, 178, 227, 502, 156, 486, 136, 285, 353, 305, 278, 97, 100]
ss1-3	[553, 571, 487, 52, 104, 227, 486, 290, 92, 576]
ss1-4	[371, 24, 571, 145, 395, 375, 545, 483, 278, 30]
ss1-5	[571, 104, 610, 114, 92, 303]
ss1-6	[571, 8, 52, 156, 486, 595]
ss1-7	[277, 533, 405, 227, 156, 285, 511]
ss1-8	[553, 145, 565, 375, 56, 483]
ss1-9	[387, 16, 12, 355, 447, 503, 546, 192]
ss1-10	[252, 108]
ss1-11	[267, 605, 140, 405, 227, 234, 257]
ss1-12	[565, 48, 56, 546]

Code	Paper IDs
ss2-1	[538, 233, 299, 40, 49, 162, 548, 187, 563, 463, 265, 195, 42, 41, 154, 94, 59, 231, 376, 432, 608, 251, 159, 53, 607, 203, 214, 200, 236, 254, 622, 202, 606, 193, 560, 465, 365, 526, 366, 181, 336, 134, 109, 453, 544, 582, 270, 335, 158, 168, 591, 230, 448, 588, 39, 210, 505, 129, 394, 44, 390, 112, 274, 430, 54, 423, 377, 194, 327, 564, 320, 596, 562, 211, 528, 549, 561, 130, 209]
ss2-2	[157, 311, 414, 95, 62, 412, 203, 400, 597, 313, 179, 544, 454, 445, 542, 220, 401, 419, 342, 372, 106, 23, 390, 413, 598, 327, 345]
ss2-3	[498, 363, 95, 323, 33, 507, 510, 559, 478, 480, 433, 287, 552, 459, 454, 220, 158, 476, 372, 394, 106, 122, 69, 274, 378, 93, 564]
ss2-4	[614, 584, 263, 507, 244, 504, 376, 99, 397, 539, 445, 35, 536, 282, 377, 276, 126, 602]
ss2-5	[498, 548, 323, 510, 559, 296, 433, 560, 453, 438, 544, 19, 270, 105, 269, 394, 44, 23, 117, 122, 69, 490]
ss2-6	[507, 22, 159, 214, 559, 438, 450, 541, 122]
ss2-7	[554, 414, 518, 611, 53, 412, 365, 313, 419, 372, 129, 430, 54, 130]

Code	Paper IDs
ss2-8	[475, 59, 592, 236, 254, 544, 450, 541, 274, 418]
ss2-9	[414, 263, 195, 42, 200, 622, 109, 453, 582, 230, 509, 327]
ss2-10	[177, 510, 478, 402, 220, 297, 594]
ss2-11	[311, 316, 159, 282]
ss2-12	[195, 317, 214, 560, 327]
ss3-1	[417, 479, 307, 110, 119, 128, 385, 577, 189, 573, 142, 625, 626, 172, 489, 273, 295, 621, 266]
ss3-2	[369, 172, 298]
ss3-3	[85]
ss3-4	[298]
ss3-5	[341]
ss3-6	[479, 85, 87, 142, 273, 298]
ss3-8	[172, 458]
ss3-9	[369, 110, 573, 266]
ss3-10	[422]
ss3-12	[479, 618]
ss4-2	[604]
ss4-3	[368, 425]

Code	Paper IDs
ss4-4	[604]
ss4-10	[425]
ss5-1	[380, 399, 96, 437, 615, 183, 271, 88, 239, 612, 196, 79, 529, 124, 18, 420, 558, 388, 593, 300, 78, 533]
ss5-2	[440, 380, 262, 337, 272, 18, 291, 420, 586, 497]
ss5-3	[617, 191, 9, 61, 609, 532, 166, 370, 107, 312, 272, 238, 398]
ss5-4	[268, 180, 150, 27, 530, 512, 275, 36, 543, 442]
ss5-5	[86, 440, 89, 191, 314, 343, 107, 344, 11, 420, 558]
ss5-6	[352, 149, 362, 286, 239, 190, 601, 529, 497]
ss5-7	[141, 96, 249, 183, 612, 420, 533]
ss5-8	[399, 96, 615, 271, 88, 315, 388, 398]
ss5-9	[183]
ss5-10	[125, 617, 389, 421, 61, 185, 166, 370, 437]
ss5-11	[21, 10, 599, 312, 456, 315]
ss5-12	[141, 149, 241, 101, 176, 79]

Table D.7: The table lists the variable codes used as superscripts in Table D.4, which summarizes device-related reporting across the top 12 application areas in haptic research. Table D.4 includes values for device origin, cost, technology used, and body laterality. Each superscript code in Table D.4 corresponds to an entry here, where the full list of contributing paper identifiers is provided.

Code	**Paper IDs**
do1-1	[553, 40, 187, 195, 42, 307, 399, 565, 94, 96, 119, 128, 432, 608, 385, 577, 53, 607, 214, 183, 189, 271, 236, 573, 429, 533, 196, 405, 56, 79, 489, 447, 158, 483, 168, 230, 448, 210, 253, 273, 388, 303, 112, 274, 430, 621, 194, 564, 320, 78, 528, 240, 533, 130, 235]
do1-2	[62, 337]
do1-3	[553, 498, 368, 487, 85, 191, 609, 166, 107, 433, 158, 92, 274, 398, 378, 487, 564]
do1-4	[371, 268, 614, 150, 536, 483, 442, 602]
do1-5	[498, 191, 314, 343, 107, 610, 296, 433, 19, 92, 490, 303]
do1-6	[352, 149, 362, 286, 85, 22, 87, 214, 190, 273]
do1-7	[96, 611, 53, 183, 533, 405, 430, 533, 130]
do1-8	[553, 399, 565, 96, 271, 236, 56, 483, 388, 274, 398]
do1-9	[195, 42, 183, 573, 12, 447, 230, 509]
do1-10	[125, 252, 389, 166, 422]

Code	Paper IDs
do1-11	[267, 405]
do1-12	[149, 195, 565, 618, 241, 101, 214, 176, 56, 79]
do2-1	[538, 417, 299, 525, 380, 548, 623, 605, 563, 339, 463, 265, 195, 307, 110, 16, 565, 96, 59, 231, 376, 128, 437, 251, 203, 615, 189, 48, 104, 200, 88, 573, 14, 622, 585, 202, 606, 560, 465, 365, 537, 526, 326, 181, 239, 109, 453, 612, 544, 56, 582, 172, 529, 124, 335, 18, 225, 234, 483, 591, 285, 588, 511, 39, 505, 129, 394, 44, 420, 558, 390, 257, 266, 256, 194, 327, 131, 593, 300, 596, 562, 211, 549, 576, 465, 561, 546, 209, 30, 228]
do2-2	[157, 155, 440, 380, 262, 311, 414, 369, 95, 387, 604, 357, 58, 412, 203, 48, 104, 400, 597, 178, 313, 272, 179, 544, 454, 445, 542, 220, 172, 401, 502, 419, 18, 342, 486, 136, 285, 372, 106, 291, 23, 420, 390, 353, 586, 305, 278, 298, 413, 97, 598, 327, 497, 604, 345, 100]
do2-3	[363, 95, 323, 33, 571, 507, 617, 85, 52, 9, 61, 510, 532, 107, 425, 312, 104, 559, 478, 287, 552, 459, 272, 454, 220, 238, 476, 486, 290, 372, 394, 106, 69, 576]

Code	Paper IDs
do2-4	[24, 584, 180, 571, 263, 507, 244, 604, 504, 376, 99, 397, 27, 530, 395, 375, 512, 545, 445, 35, 275, 36, 543, 483, 278, 298, 276, 604, 126, 602, 30]
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do2-6	[352, 571, 507, 362, 8, 85, 52, 559, 239, 438, 601, 529, 486, 450, 541, 298, 595, 497]
do2-7	[554, 414, 518, 96, 277, 249, 412, 365, 313, 612, 419, 285, 511, 372, 129, 420]
do2-8	[475, 565, 96, 59, 592, 375, 615, 88, 315, 544, 56, 172, 483, 450, 541, 418]
do2-9	[414, 369, 263, 195, 387, 110, 16, 200, 573, 622, 109, 453, 582, 355, 266, 327, 503, 546, 192]
do2-10	[252, 617, 177, 108, 421, 61, 510, 185, 437, 425, 478, 402, 220, 594]
do2-11	[311, 605, 140, 316, 10, 599, 312, 456, 315, 234, 257]
do2-12	[195, 565, 317, 48, 560, 56, 327, 546]
do3-1	[417, 380, 339, 565, 159, 464, 377]

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do3-6	[571, 507, 159, 156, 122]
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do3-8	[565, 315]
do3-10	[297]
do3-11	[21, 10, 159, 315, 282]
do3-12	[565]
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do4-12	[479]
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Code	Paper IDs
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do5-7	[141]
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do6-2	[227]
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do6-5	[270, 11]
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do6-11	[227]
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cd1-2	[155, 414, 369, 203, 298]

Code	Paper IDs
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cd1-5	[453, 122]
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cd1-7	[141, 414, 518]
cd1-9	[414, 369, 453]
cd1-11	[234]
cd1-12	[141]
cd2-1	[110]
cd2-4	[180]
cd2-9	[110]
cd3-1	[168]
cd3-2	[155]
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cd4-1	[16, 483]
cd4-2	[486]
cd4-3	[486]
cd4-4	[275, 483]

Code	Paper IDs
cd4-6	[486]
cd4-8	[483]
cd4-9	[16]
cd5-4	[275]
cd6-1	[529]
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Code	Paper IDs
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Code	Paper IDs
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tu1-5	[344]

Code	Paper IDs
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tu1-10	[125, 252]
tu1-11	[599]
tu2-1	[119, 200]
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tu2-4	[24]
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tu4-7	[277]

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tu6-4	[571, 507, 395]
tu6-5	[571, 104, 303]
tu6-6	[571, 507]
tu6-7	[227]
tu6-11	[10, 227, 234]
tu7-1	[538, 605, 59, 432, 437, 560, 465, 533, 529, 270, 483, 591]
tu7-2	[95, 486]
tu7-3	[95, 487, 191, 559, 476, 486, 378]
tu7-4	[614, 483]
tu7-5	[89, 191, 314, 559, 610, 296, 560, 270, 11]
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tu7-7	[533]
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tu8-6	[541]
tu8-8	[541]
tu9-6	[450]
tu9-8	[450]
tu10-1	[553, 203, 236, 254, 429, 18, 273, 430, 235]
tu10-2	[203, 18, 486]
tu10-3	[553, 486]
tu10-6	[486, 273]
tu10-7	[430]
tu10-8	[553, 236, 254]
tu10-9	[12]

Code	Paper IDs
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tu11-4	[584, 180, 571, 263, 507, 244, 376, 397, 27, 375, 35, 275, 483, 282, 278, 298, 377, 276, 442]
tu11-5	[86, 323, 571, 191, 343, 510, 107, 104, 559, 296, 560, 114, 453, 544, 270, 105, 394, 44, 23, 420, 558, 117, 69, 341]
tu11-6	[571, 507, 85, 87, 159, 559, 239, 156, 486, 298, 595, 497]
tu11-7	[518, 412, 533, 612, 156, 285, 511, 372, 129, 420]
tu11-8	[475, 565, 375, 544, 172, 483, 418]
tu11-9	[263, 195, 16, 573, 109, 453, 582, 355, 503, 546, 192]

Code	Paper IDs
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tu11-11	[311, 605, 140, 316, 10, 159, 312, 282, 257]
tu11-12	[195, 565, 317, 241, 101, 48, 176, 560, 546]
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tu12-3	[323, 33, 571, 507, 85, 191, 370, 312, 104, 478, 433, 287, 272, 454, 220, 238, 158, 486, 290, 92, 372, 394, 122, 274, 398, 93]
tu12-4	[268, 571, 507, 145, 150, 244, 504, 397, 27, 539, 375, 512, 545, 445, 35, 275, 536, 543, 298, 126, 602, 30]

Code	Paper IDs
tu12-5	[440, 548, 323, 571, 191, 314, 104, 433, 453, 438, 544, 269, 92, 394, 44, 558, 122, 490, 341, 303]
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tu12-7	[141, 414, 518, 53, 412, 183, 365, 612, 285, 511, 372, 54, 533, 130]
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tu12-9	[414, 369, 195, 42, 387, 110, 16, 183, 573, 622, 453, 582, 230, 266, 546]
tu12-10	[370, 478, 402, 220, 297, 594]
tu12-11	[605, 312, 315, 257]
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tu13-1	[563, 88, 202, 537]
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tu13-6	[52]
tu13-8	[88]

Code	Paper IDs
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tu16-3	[553, 33, 576]
tu16-5	[89, 314, 11]
tu16-7	[533]
tu16-8	[553]
tu17-1	[553, 405, 464]
tu17-3	[553, 498, 368, 287, 552, 238, 122]
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tu18-2	[220]

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tu18-10	[220]
tu19-1	[615, 45, 420]
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tu19-7	[420]
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tu19-10	[422]
tu20-1	[88, 585, 582, 390, 327, 211]
tu20-2	[390, 327]
tu20-8	[88]
tu20-9	[582, 327]
tu20-12	[327]
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Code	Paper IDs
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tu21-4	[571, 545, 445, 275, 278]
tu21-5	[571, 104, 114, 453, 438, 544, 394, 23, 420, 69]
tu21-6	[571, 438, 601, 156, 486, 497]
tu21-7	[412, 156, 285, 129, 420]
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tu21-10	[220, 297]
tu21-11	[10, 456, 234, 257]
tu21-12	[48, 327, 546]
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bl1-4	[397, 298]
bl1-5	[105]
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Code	Paper IDs
bl1-9	[200]
bl2-1	[299, 525, 49, 162, 623, 16, 231, 128, 432, 608, 385, 607, 88, 236, 366, 109, 405, 56, 225, 45, 511, 39, 44, 420, 112, 621, 300, 596, 78, 533, 235]
bl2-2	[155, 414, 604, 58, 178, 420, 353, 298, 604]
bl2-3	[85, 510, 166, 107, 559, 378, 93]
bl2-4	[244, 604, 282, 298, 604]
bl2-5	[343, 510, 107, 559, 610, 44, 420, 117]
bl2-6	[8, 85, 559, 298]
bl2-7	[141, 414, 405, 511, 420, 533]
bl2-8	[475, 88, 236, 56, 418]
bl2-9	[414, 16, 109]
bl2-10	[389, 108, 510, 185, 166]
bl2-11	[405, 282]
bl2-12	[141, 56]
bl3-1	[553, 417, 233, 202, 193, 465, 612, 196, 172, 168, 230, 273, 388, 390, 256, 377, 465, 130]
bl3-2	[179, 445, 172, 502, 419, 342, 136, 372, 23, 390, 97, 345]

Code	Paper IDs
bl3-3	[553, 323, 617, 372]
bl3-4	[371, 145, 530, 545, 445, 35, 377]
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bl3-6	[352, 190, 273]
bl3-7	[612, 419, 372, 130]
bl3-8	[553, 145, 315, 172, 388]
bl3-9	[355, 230, 192]
bl3-10	[617]
bl3-11	[267, 456, 315]
bl3-12	[176]
bl4-1	[607, 511, 257]
bl4-2	[414, 220]
bl4-3	[287, 220]
bl4-6	[595]
bl4-7	[414, 511]
bl4-9	[414]
bl4-10	[220, 297]
bl4-11	[257]

Code	Paper IDs
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bl5-2	[157, 311, 357, 278]
bl5-3	[52, 9, 61, 69, 576]
bl5-4	[584, 145, 376, 27, 539, 395, 275, 543, 483, 278, 276]
bl5-5	[548, 314, 453, 11, 69]
bl5-6	[479, 52, 159, 529]
bl5-7	[277, 249]
bl5-8	[145, 59, 592, 271, 483, 458]
bl5-9	[110, 453, 447, 266]
bl5-10	[177, 421, 61]
bl5-11	[21, 311, 316, 599, 159]
bl5-12	[479, 317]
bl6-1	[96, 437, 577, 366, 593, 564, 562, 549]
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bl6-3	[191, 532, 370, 425, 564]
bl6-4	[545, 445]
bl6-5	[191, 105]

Code	Paper IDs
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bl6-8	[96]
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bl7-1	[553, 233, 40, 605, 88, 429, 202, 193, 560, 465, 533, 181, 134, 612, 196, 168, 45, 591, 230, 273, 129, 394, 558, 388, 390, 303, 256, 377, 465, 533, 130]
bl7-2	[440, 95, 272, 419, 372, 106, 390, 598]
bl7-3	[553, 95, 478, 459, 272, 372, 394, 106, 398, 93]
bl7-4	[371, 145, 99, 545, 35, 377]
bl7-5	[440, 560, 394, 558, 341, 303]
bl7-6	[352, 190, 273]
bl7-7	[611, 533, 612, 419, 372, 129, 533, 130]
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bl7-10	[478]
bl7-11	[267, 605, 315]

Code	Paper IDs
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bl8-5	[105]
bl8-6	[497]
bl8-9	[582]
bl8-10	[125, 402]
bl8-11	[10]
bl9-1	[538, 380, 187, 563, 339, 463, 265, 195, 42, 307, 41, 154, 399, 565, 94, 119, 59, 53, 203, 615, 214, 183, 189, 48, 104, 254, 573, 14, 622, 132, 606, 365, 326, 239, 336, 142, 625, 544, 626, 79, 227, 270, 335, 18, 158, 234, 285, 448, 588, 210, 505, 464, 253, 274, 430, 54, 423, 194, 327, 131, 320, 211, 528, 240, 546, 30, 228]
bl9-2	[380, 262, 369, 387, 62, 412, 203, 337, 48, 104, 400, 597, 313, 544, 454, 445, 542, 227, 401, 18, 156, 486, 285, 291, 305, 327, 100]

Code	Paper IDs
bl9-3	[498, 363, 368, 33, 571, 507, 609, 312, 104, 480, 433, 287, 552, 454, 227, 238, 158, 476, 486, 290, 92, 122, 274]
bl9-4	[268, 614, 24, 180, 571, 263, 507, 150, 504, 375, 512, 445, 536, 36, 126, 442, 602, 30]
bl9-5	[498, 86, 89, 571, 344, 104, 296, 433, 114, 438, 544, 19, 270, 269, 92, 122, 490]
bl9-6	[149, 571, 507, 286, 22, 87, 214, 239, 142, 438, 601, 156, 486, 450, 541, 122]
bl9-7	[554, 518, 53, 412, 183, 365, 313, 227, 156, 285, 430, 54]
bl9-8	[399, 565, 59, 375, 615, 254, 544, 450, 541, 274]
bl9-9	[369, 263, 195, 42, 387, 183, 573, 622, 12, 509, 327, 503, 546]
bl9-10	[422]
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bl9-12	[149, 195, 565, 618, 214, 48, 79, 327, 546]

Table D.8: The table lists the variable codes used as superscripts in Table D.1, which summarizes evaluation techniques and metrics reported across the top 12 application areas in haptic research. Table D.1 includes values for behavioral, subjective, and physiological methods, as well as specific metric types such as force, perceptual, temporal-spatial, and cognitive-emotional. Each superscript code in Table D.1 corresponds to an entry here, where the full list of contributing paper identifiers is provided.

Code	**Paper IDs**
et1-1	[417, 40, 42, 399, 59, 231, 376, 128, 608, 385, 251, 577, 159, 615, 214, 48, 104, 88, 573, 622, 560, 625, 626, 56, 79, 270, 158, 234, 45, 285, 588, 39, 505, 464, 253, 257, 112, 54, 377, 194, 596, 78]
et1-2	[157, 95, 604, 58, 337, 48, 104, 178, 445, 486, 285, 372, 291, 305, 278, 298, 413, 97, 598, 100]
et1-3	[498, 95, 323, 487, 85, 191, 9, 609, 510, 166, 107, 104, 559, 433, 158, 476, 486, 290, 92, 372, 378]
et1-4	[371, 180, 263, 150, 244, 604, 376, 99, 27, 530, 375, 512, 445, 275, 36, 543, 278, 298, 377, 276]
et1-5	[498, 323, 191, 314, 343, 510, 107, 104, 559, 610, 296, 433, 560, 270, 11, 105, 269, 92]
et1-6	[352, 149, 286, 8, 85, 22, 87, 159, 214, 559, 190, 486, 298, 595]
et1-7	[285, 372, 54]

Code	Paper IDs
et1-8	[399, 59, 375, 615, 88, 56]
et1-9	[263, 42, 573, 622]
et1-10	[389, 108, 510, 185, 166]
et1-11	[21, 10, 599, 159, 234, 257]
et1-12	[149, 618, 317, 101, 214, 48, 176, 560, 56, 79]
et2-1	[553, 40, 49, 162, 479, 42, 533, 529, 489, 335, 439, 230, 588, 273, 295, 423, 562, 211, 561]
et2-2	[178, 179, 345, 100]
et2-3	[553, 93]
et2-4	[35]
et2-6	[479, 601, 529, 273]
et2-7	[249, 533]
et2-8	[553]
et2-9	[42, 355, 230]
et2-10	[177, 402]
et2-12	[479]

Code	Paper IDs
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et3-2	[387, 62, 203, 313, 542, 401, 18, 156, 342, 136, 372, 390, 353, 305, 278, 413]
et3-3	[363, 191, 609, 312, 372, 274, 576]
et3-4	[371, 24, 263, 150, 244, 397, 539, 395, 35, 536, 543, 483, 278, 442, 602]
et3-5	[191, 11, 44, 341]
et3-6	[156]
et3-7	[554, 141, 611, 183, 313, 612, 156, 372]
et3-8	[615, 483, 274]
et3-9	[263, 42, 387, 110, 16, 183, 622, 447, 230, 546]
et3-11	[312]
et3-12	[141, 546]

Code	Paper IDs
et4-1	[538, 553, 233, 299, 40, 525, 49, 380, 548, 623, 479, 563, 339, 463, 265, 195, 42, 307, 41, 154, 110, 16, 565, 94, 432, 607, 203, 615, 214, 183, 271, 48, 104, 200, 88, 573, 14, 622, 202, 606, 365, 537, 526, 366, 326, 239, 336, 453, 612, 196, 405, 625, 626, 56, 582, 172, 529, 489, 447, 335, 225, 591, 230, 448, 588, 511, 39, 210, 505, 464, 253, 273, 129, 394, 295, 303, 257, 112, 274, 430, 621, 266, 54, 423, 256, 377, 327, 131, 593, 300, 564, 320, 78, 528, 549, 576, 240, 546, 130, 209, 235, 30, 228]
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et4-3	[553, 498, 363, 368, 33, 52, 61, 370, 104, 559, 480, 433, 287, 552, 459, 454, 220, 238, 486, 372, 394, 106, 122, 69, 274, 398, 378, 93, 564, 576]
et4-4	[371, 268, 614, 24, 584, 145, 150, 604, 395, 512, 35, 275, 278, 298, 377, 602, 30]
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et4-8	[553, 475, 145, 565, 615, 271, 88, 56, 172, 274, 398, 418]
et4-9	[414, 195, 42, 110, 16, 183, 200, 573, 622, 453, 12, 582, 355, 447, 230, 266, 509, 327, 546, 192]
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et5-1	[538, 553, 299, 525, 49, 187, 339, 42, 307, 41, 154, 110, 16, 399, 565, 94, 119, 437, 53, 607, 203, 214, 183, 189, 271, 104, 200, 88, 236, 254, 573, 622, 429, 585, 132, 202, 606, 193, 560, 465, 533, 365, 526, 366, 326, 181, 239, 336, 134, 109, 142, 453, 612, 196, 405, 625, 544, 626, 56, 79, 582, 227, 529, 124, 335, 18, 158, 225, 45, 591, 285, 230, 448, 588, 511, 39, 210, 505, 464, 273, 129, 394, 44, 420, 558, 388, 295, 112, 274, 430, 621, 266, 54, 423, 327, 131, 593, 576, 561, 546, 130, 209, 235, 30]

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et5-7	[554, 141, 518, 53, 183, 533, 365, 313, 612, 405, 227, 419, 156, 285, 511, 372, 129, 420, 430, 54, 130]
et5-8	[553, 399, 565, 592, 375, 271, 88, 236, 254, 315, 544, 56, 450, 541, 388, 274, 458]
et5-9	[369, 263, 42, 387, 110, 16, 183, 200, 573, 622, 109, 453, 12, 582, 230, 266, 509, 327, 503, 546]
et5-10	[421, 437, 425, 478, 402, 220, 297, 422, 594]

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et5-12	[141, 565, 241, 214, 176, 560, 56, 79, 327, 546]
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mu1-2	[357, 454, 372, 100]
mu1-3	[323, 571, 52, 312, 454, 372, 122, 564]
mu1-4	[371, 268, 614, 24, 584, 180, 571, 263, 507, 150, 244, 604, 376, 99, 27, 530, 539, 512, 445, 35, 275, 536, 36, 543, 278, 298, 276, 602, 30]
mu1-5	[323, 571, 114, 438, 270, 269, 122]
mu1-6	[352, 571, 52, 438, 122]
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mu2-2	[155, 104, 178, 179, 454, 542, 401, 106, 390, 586, 305, 413, 327, 100]
mu2-3	[553, 191, 510, 104, 480, 454, 394, 106, 398]
mu2-4	[571, 244, 602]
mu2-5	[191, 510, 104, 394, 44]
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mu2-8	[582, 327, 546, 192]
mu2-9	[553, 475, 88, 236, 398]
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mu3-3	[95, 323, 571, 507, 487, 85, 191, 609, 510, 166, 107, 312, 559, 433, 220, 158, 476, 486, 92, 394, 274, 398, 378]
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mu3-6	[352, 149, 571, 507, 362, 286, 8, 85, 22, 87, 559, 529, 156, 486, 450, 298, 595]
mu3-7	[414, 183, 533, 313, 156, 285, 511, 430]
mu3-8	[414, 263, 183, 573, 355]
mu3-9	[565, 615, 544, 56, 450, 274, 398]
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mu4-4	[268, 24, 180, 571, 145, 150, 375, 512, 545, 445, 536, 36, 543, 282, 278, 298, 377, 276]
mu4-5	[571, 191, 343, 560, 105]
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mu5-1	[40, 525, 380, 548, 339, 195, 42, 41, 399, 565, 94, 59, 128, 385, 607, 615, 214, 183, 271, 48, 104, 88, 622, 202, 193, 365, 625, 626, 56, 79, 588, 511, 39, 420, 112, 621, 54, 377, 327, 78, 561]

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mu5-2	[155, 380, 414, 337, 48, 104, 454, 445, 542, 486, 372, 420, 305, 278, 298, 413, 598, 327]
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mu5-5	[498, 548, 89, 323, 571, 191, 314, 343, 107, 104, 559, 610, 269, 420, 122, 490]
mu5-6	[352, 149, 571, 286, 87, 214, 559, 190, 486, 122, 298]
mu5-7	[554, 414, 183, 365, 511, 372, 420, 54]
mu5-8	[414, 195, 42, 183, 622, 327]
mu5-9	[145, 399, 565, 59, 375, 615, 271, 88, 56, 398]
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mu6-3	[553, 363, 61, 370, 425, 287, 238, 476]
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mu6-8	[12]
mu6-9	[553]
mu6-10	[61, 370, 425]
mu7-1	[538, 553, 233, 299, 525, 162, 380, 623, 479, 187, 563, 463, 265, 195, 42, 307, 154, 110, 16, 565, 94, 119, 432, 385, 437, 607, 203, 615, 183, 189, 271, 48, 104, 200, 88, 254, 14, 429, 606, 465, 537, 526, 366, 326, 181, 239, 336, 134, 109, 142, 453, 612, 196, 405, 544, 626, 79, 582, 227, 172, 124, 489, 447, 158, 225, 591, 285, 230, 448, 39, 210, 505, 253, 273, 129, 394, 420, 558, 388, 295, 390, 303, 274, 430, 621, 266, 423, 256, 194, 327, 131, 300, 320, 211, 549, 576, 240, 533, 130, 209, 235, 30]
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Code	Paper IDs
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mu7-6	[479, 149, 571, 507, 22, 239, 190, 142, 438, 601, 273, 541, 298, 497]
mu7-7	[554, 141, 518, 611, 412, 183, 313, 612, 405, 227, 419, 285, 129, 420, 430, 533, 130]
mu7-8	[369, 263, 195, 42, 387, 110, 16, 183, 200, 109, 453, 12, 582, 447, 230, 266, 509, 327, 503]
mu7-9	[553, 145, 565, 592, 375, 615, 271, 88, 254, 315, 544, 172, 541, 388, 274, 398, 458, 418]
mu7-10	[510, 437, 478, 402, 297, 422]
mu7-11	[141, 479, 149, 195, 565, 48, 79, 327]
mu7-12	[21, 267, 311, 316, 312, 315, 405, 227, 282]