

Distal-Haptic Touchscreens: Understanding the User Experience of Vibrotactile Feedback Decoupled from the Touch Point

Mihail Terenti

MintViz Lab, MANSiD Research Center
Ștefan cel Mare University of Suceava
Suceava, Romania
mihail.terenti@usm.ro

Radu-Daniel Vatavu

MintViz Lab, MANSiD Research Center
Ștefan cel Mare University of Suceava
Suceava, Romania
radu.vatavu@usm.ro



Figure 1: Distal haptics at various body locations—finger, wrist, forearm, or even more distant at whole-body level—provide confirmatory feedback for touch input, especially useful for touchscreens without built-in haptics, like those in these photos. Although consumer wearables—electronic rings, smartwatches, arm bands—can readily deliver distal haptics to connected touchscreens, the novel user experience evoked by spatially decoupling input and output is unknown to interaction designers.

Abstract

We examine the user experience of distal haptics for touchscreen input through confirmatory vibrations of on-screen touches at various on-body locations. To this end, we introduce the *Distal Haptics Continuum*, a conceptual framework of haptic feedback delivery across the body, organized along the dimensions of *Body Laterality* and *Proximity* to the touch point. Our results, from three experiments involving 45 participants and 16 locations across the *hand*, *arm*, and *whole body*, reveal a strong preference for distal haptics over no haptics at all, despite the spatial decoupling from the touch point, with the index finger yielding the highest user experience.

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CHI '25, Yokohama, Japan

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ACM ISBN 979-8-4007-1394-1/25/04
<https://doi.org/10.1145/3706598.3713555>

We also identify additional on-body locations—the adjacent fingers, wrist, and abdomen—that unlock distinctive design opportunities. Building on our insights, demonstrating haptics effectiveness even when distant from the touch point, we outline implications for integrating various on-body locations, well beyond the index finger, into the user experience of touchscreen input.

CCS Concepts

• **Human-centered computing** → **Touch screens; Haptic devices; Gestural input.**

Keywords

User experience, haptics, distal haptics, vibrotactile feedback, touch input, touchscreens

ACM Reference Format:

Mihail Terenti and Radu-Daniel Vatavu. 2025. Distal-Haptic Touchscreens: Understanding the User Experience of Vibrotactile Feedback Decoupled from the Touch Point. In *CHI Conference on Human Factors in Computing Systems (CHI '25)*, April 26-May 1, 2025, Yokohama, Japan. ACM, New York, NY, USA, 19 pages. <https://doi.org/10.1145/3706598.3713555>

1 Introduction

Touch input is mainstream on a diversity of digital devices, where it enables fast [57] and intuitive [117] interactions, proves effective in eyes-free contexts of use [111], and has found large adoption in public displays [79]. Moreover, touch input is gaining new ground, notably in on-body computing, where the user’s body serves for input [11], and in pervasive computing environments, where everyday objects, such as chairs [3], are appropriated for always-available input. However, touch-based interactions still present specific design challenges, such as the difficulty of accurately acquiring small targets [13,43] or the limited expressiveness of on-screen haptics compared to the tactile richness of real-world textures [8], with detrimental impact on user experience (UX).

To address such challenges, extensive research has focused on haptic feedback accompanying touchscreen input, with numerous benefits [18,65,82,83]. Even a small amount of vibrotactile feedback applied to the user’s hand to induce the experience of a “soft click” has been proven to enhance touch input performance [35]. Furthermore, vibrotactile confirmation reduces the need for visual attention: knowing that the touch command was successful, users can quickly move to the next target [35,40]. Unfortunately, the expressive capabilities of mainstream haptics technology in mobile devices remain limited [8], while technical solutions for larger screens [9,32,45] are still in early stages of development.

An intriguing alternative to device built-in haptics involves providing vibrotactile feedback through wearables [101], e.g., a smart ring [60] or smartwatch [42], during touchscreen input. This approach not only democratizes the advantages of vibrotactile feedback for all touchscreens, especially those lacking built-in haptics, but also facilitates stimulation of different body parts besides the fingertip [1,91,100] and creates an additional output channel for delivering information to users [28,72]; see Figure 1 for examples involving various touchscreens. Unfortunately, research into the UX of *distal, on-body haptics* accompanying touchscreen input remains severely limited, where the few works in this space have primarily centered on user performance or system design [42,60,70]. Two recent studies [100,101] are currently the only investigations into distal haptics UX for touchscreen input, but their findings are limited by a narrow focus on just a few regions of the arm—the index finger, wrist, and forearm—in close proximity to the touch point. In the context where consumer wearables become increasingly available for various body parts—including glasses, vests, and footwear—there is untapped potential for exploring distal haptics in various contexts involving touchscreens, such as eyes-free input [120], ambient displays [6], in-vehicle interactions [81], and mixed reality [97]. Unfortunately, the UX of distal haptics at on-body locations beyond the arm remains largely unexplored for touchscreen input, leaving designers unable to draw on existing knowledge. In this context, our contributions are as follows:

- (1) We formalize distal haptics for touchscreen input with the *Distal Haptics Continuum*, a conceptual framework that structures body locations for delivering distal haptics based on two key dimensions: *Body Laterality* (i.e., the same or opposite side of the body as the hand performing touch input) and *Proximity* (i.e., the distance, in a referential system centered on the user’s body, to the touch point on the screen).

- (2) We report empirical results from three experiments with 45 participants to assess the UX of distal haptics during touchscreen input across 16 locations spanning three body zones—*hand*, *arm*, and *whole-body*—progressively farther from the touch point. Our results reveal a preference for the index finger, which evoked the highest user experience (DHUX=76.8 on our dedicated 0 to 100 distal-haptic UX scale), and high ratings for other locations—the middle (69.0) and thumb (66.7) fingers at *hand* level, the wrist (67.6) at *arm* level, and the abdomen (72.1) at *whole-body* level—revealing the effectiveness of distal haptics beyond the index finger.
- (3) Drawing from our findings, we propose a set of practical implications for innovative interactions that harness wearable devices for implementing distal haptics at various on-body locations to enrich the UX of touchscreen input.

2 Related Work

Prior work on haptics for interactive systems has focused on understanding users’ discrimination abilities of stimuli presented at various on-body locations and their impact on user performance. Our research builds upon this foundation, focusing on the examination of vibrotactile feedback through the UX it evokes. In the following, we structure our discussion of prior work based on the on-body locations used for delivering vibrotactile stimuli.

2.1 User Perception of Vibrotactile Stimuli

2.1.1 Finger and hand-level stimuli. Seim et al. [91] evaluated users’ ability to discriminate vibrotactile stimuli, represented by single and multiple pulses delivered simultaneously on different fingers via up to four motors. They found that dorsal placements determined consistent localization accuracy, placements on the ventral side resulted in higher accuracy as the distance from the fingertip increased, and chord recognition involving multiple simultaneously presented stimuli degraded as their number increased. Also, linear resonant actuators (LRAs) determined a decrease in accuracy of 10.1% for ventral locations compared to eccentric rotating mass (ERM) motors. McIntosh et al. [71] examined fingertip-level haptics, implemented as electromagnetic pulse bursts using a hand-wound coil for around-device interactions, and found that combining a 12 ms signal duration with 4 ms pulses yielded the highest perceived strength. At the *fingers* and *hand* level, Luzhnica and Veas [67] reported exceptional accuracy (97%), achieved within five hours of training, for letters encoded with vibrotactile stimuli using a layout of motors placed on the fingers and dorsal side of the hand. In such setups involving multiple stimuli, vibrotactile masking can occur, where one stimulus affects the detectability of another, e.g., Verrillo et al. [106] reported that pulses at the finger and hand levels can be effectively masked within the frequency range of maximum Pacinian system sensitivity (300 Hz), even when the stimuli are delivered at different locations—such as the thenar eminence and the distal phalanx of the index finger, respectively.

2.1.2 Wrist-level stimuli. Lee and Starner [62] discovered up to 99% recognition accuracy of twenty-four vibrotactile stimuli of various intensity, starting point, temporal pattern, and direction at the wrist level. Vibration intensity (weak, 0.43g/133Hz vs. strong,

0.71g/175Hz) received the lowest accuracy (47.0%) and was evaluated as the most difficult parameter to recognize, while the temporal pattern (dash for steady vs. dots for pulsed vibrations) the easiest (86.4%). Liao et al. [65] reported effective discrimination (85.9%) of twenty-six spatiotemporal stimuli inspired by the EdgeWrite [118] alphabet—a set of unistrokes fully specified by the order of a square’s corners. For example, the letter “b” is rendered with vibrations in sequence starting from the top-left corner, continuing to the bottom-left, bottom-right, and returning to the bottom-left square’s corner, implemented on a watch-back vibrotactile array display. Elvitigala et al. [31] evaluated user perception of two-bit tactons [15] delivered via spatiotemporal encoding by pairs of motors placed on the *fingers* and *wrist*, e.g., the actuators on the middle and index fingers vibrate in sequence. They reported high recognition accuracy (92%), significantly higher for the fingers compared to the wrist. In a longitudinal study, Cauchard et al. [18] reported an 88.7% accuracy rate for ActiVibe, a set of ten vibrotactile icons designed to convey progress information on smartwatches as a discrete value between one and ten. For example, a continuous ActiVibe vibration design represents progress through its duration, while a series of short pulses indicates progress through the number of discrete stimuli.

2.1.3 Forearm-level stimuli. Schönauer et al. [88] examined discrimination ability for stimuli of varying duration, between 250 ms and 1750 ms, and various intensity, between 0.2g/0.9V and 0.85g/3V, represented by forearm-level single and multiple pulses accompanying touch and mid-air gestures for smartphone interactions. They reported good recognition accuracy for either the temporal pattern of the stimuli (79.7%) or their intensity (67.8%), but the combined evaluation of both attributes exhibited significantly lower accuracy (55.4%). D’Amour and Harris [25] evaluated forearm-level tactile sensitivity with vibrotactile masking on the opposite arm, and reported sensitivity decreasing by over 3 dB when the arms were touching and by 0.5 dB when held parallel. This finding, which reveals a long-range inhibitory effect in tactile perception, reveals a close relationship between the two body sides, despite spatial separation, and recommends examination of distal haptics on the opposite side to the arm performing touch input, which we integrate in our framework in Section 3. Wang et al. [109] investigated localization accuracy of stimuli presented simultaneously on both arms through haptic bands worn near the elbow and shoulder. They found that accuracy decreased linearly as the number of stimuli increased, falling to 27.8% when three stimuli were presented.

2.1.4 Head-level stimuli. Diener et al. [26] studied user localization of vibrotactile stimuli delivered at the head level in the form of single pulses of 30 ms, 100 ms, and 250 ms, implemented at 19 different locations via a head-worn device, and reported the occipital, parietal, and temple regions with heightened sensitivity, although vibrations on the *temples* were felt mildly discomforting. Nukarinen et al. [74] compared *head* and *wrist*-level vibrotactile feedback, represented by a 30 ms-long pulse driven using a 150 Hz sine wave, for feedback about object selection in a virtual environment, and reported that the *wrist* emerged as a more promising location. Noteworthy, their results also highlighted that even a suboptimal location, such as the *temples*, yields superior performance compared to having no vibrotactile feedback at all. Head-level vibration stimuli have been largely studied for navigation assistance; see [12,50,51] for details.

2.1.5 Body-level stimuli. Other studies have examined a wider array of on-body locations. For example, by capitalizing on the observation that users attach their smartphones to different body parts for various uses, Alvina et al. [1] examined perception of vibrotactile stimuli on the *palm*, *arm*, *thigh*, and *waist*. The stimuli consist of one, two, or three sequential vibrations delivered by motors in a 2×2 layout, e.g., a diagonal pulse is created by vibrating the top-left and bottom-right motors. OmniVib, their set of eight spatiotemporal stimuli, achieved high accuracy (86.3%) with the *arm* scoring the highest (92.7%). Karuei et al. [49] explored a more extensive set of thirteen locations at the *wrist*, *arm*, *torso*, *thigh*, and *feet* levels, and found that user response time remained consistent for high-intensity vibrations, while accuracy varied across locations with the *wrists* and *spine* being the most sensitive and the *feet* and *thighs* the least. Elsayed et al. [30] investigated vibrations consisting of 500 ms-long pulses delivered to the *wrist*, *forearm*, *upper arm*, *back*, *torso*, *thigh*, and *leg* to determine optimal motor spacing for vibrotactile displays. They found heightened sensitivity in the body extremities with participants preferring the *wrist*, which was considered more comfortable than the *torso*, yet not significantly different from the *forearm* or *upper arm*. Kim et al. [54] examined recognition accuracy on the *torso* using four actuators in a rectangular layout, targeting the torso’s front, back and the waist for application in haptic vests. They reported 91% accuracy and estimated an information transfer rate of approximately 3.5 bits, sufficient to distinguish twelve patterns formed by activating and deactivating actuators, including simultaneous activation, at the *torso* level. For more details into the perception of vibrotactile stimuli, we refer to Cholewiak and Collins [21] for an overview of vibrotactile localization on the *arm*, and Cholewiak et al. [20] for a detailed discussion of vibrotactile localization on the *abdomen*.

2.2 Touchscreen Interactions Assisted by Vibrotactile Feedback

At the *palm* level, Forlines et al. [35] examined the impact of vibrotactile feedback delivered via a stylus on user performance during pointing and crossing selection tasks. Their findings revealed that even subtle vibrations, described as “soft clicks,” which simulate sensations of running the stylus over a small bump on the screen or dragging it over a thin wire, led to shorter selection times due to effective confirmation without the need for visual attention. At the *wrist* level, Henderson et al. [42] examined the impact of vibrotactile feedback delivered via a smartwatch on users’ performance in smartphone touch input tasks. They showed that distal *wrist*-level vibrations, delivered as a continuous pulse until the user either lifts their finger or exits a region around the on-screen target, significantly reduce touch target acquisition errors compared to no feedback, akin to under-the-finger vibrations delivered via the smartphone’s built-in actuator. At the *wrist* and *upper arm* levels, McAdam and Brewster [70] discovered that distal vibrotactile feedback, delivered via a smartphone in the form of 1-beat 300 ms and 3-beat 500 ms tactons [15], significantly increased text entry rates on a tabletop computer, without compromising accuracy, compared to the control condition of no vibrations.

Due to the many benefits of vibrotactile feedback, one fruitful research direction has been prototyping new devices that leverage

it for novel user experiences. For example, Le et al. [60] used a smart ring for augmenting input on an interactive tabletop, and Vatavu et al. [104] proposed an index-finger augmentation device that uses vibrations to induce the sensation of holding digital objects between the fingers. Beyond touchscreen input, Lee et al. [61] reported that tactile stimuli, delivered to the *wrist* through the Air Touch interface during mid-air interaction, effectively compensated for limited visual feedback. Freeman et al. [36] explored above-device gestures accompanied by vibrotactile feedback, which included continuous stimuli to inform the user when their hand was being tracked as well as discrete tactions, between 150 ms and 300 ms, to alert about specific events. Their results, comparing mid-air, on-screen, and finger- and wrist-level vibrations, showed no significant differences between these conditions, but a strong preference for vibrotactile feedback over its absence. Maeda et al. [69] proposed HapticAid, a wearable system for the wrist, designed to augment interactions with everyday objects. The data collected by a piezoelectric polyvinylidene fluoride film sensor placed on the index finger is amplified to drive a haptic actuator integrated into a wristband for haptic enhancement, enchantment, and empathy [68].

To the best of our knowledge, Terenti and Vatavu [100,101] conducted the sole evaluations of distal haptics UX for touchscreen input, but their findings are restricted to the *index finger*, *wrist*, and *forearm*. Given the extensive literature showing positive user perception of vibrotactile stimuli across various on-body locations from *head* to *feet*, as reviewed in Subsection 2.1, we identify a clear gap in scientific knowledge, which limits designers' ability to apply existing insights for new body-level distal haptics experiences. In this work, we build upon [100,101] to deepen our understanding of distal haptics UX by exploring a broader range of 16 on-body locations across the *hand*, *arm*, and *whole-body* levels, progressively farther from the touch point. Also, while Terenti and Vatavu [101] focused on design techniques for integrating wearable and on-screen haptics—through the addition, reinforcement, extension, and expansion of vibrotactile feedback—our approach differs by introducing a framework and providing corresponding empirical evidence on the role of body regions and their proximity to the touch point for the distal haptics UX of touchscreen input. Next, we review UX research that lays the foundation for the evaluation of haptics experience in our experiments.

2.3 Evaluating Haptics UX

While distal haptics UX for touchscreen input has seen limited exploration, UX evaluations of haptics are widespread in generic human-computer interaction. For instance, Wilson and Brewster [115] elicited valence and arousal ratings of multimodal vibrotactile, thermal, and visual stimuli for conveying emotional information. Similarly, Ooms et al. [75] assessed perceived arousal, valence, and comfort of vibrotactile stimuli presented on the palm while watching videos. Cauchard et al. [18] evaluated the perceived comfortability and annoyance of smartwatch-delivered vibrations, and Schneider et al. [87] characterized the UX of vibrotactile feedback on smartphones using duration, energy, speed, roughness, urgency, and pleasantness. Kim and Schneider [53] introduced a theoretical model of haptic experience, incorporating design parameters, usability requirements, and experiential dimensions such as harmony,

expressivity, autotelics, immersion, and realism. They argued that haptic experience is unique compared to other technological experiences, relying heavily on the cohesion between haptics and other system components. Anwar et al. [5] expanded on realism, harmony, involvement, and expressivity as key factors for multimodal haptic experiences. Terenti and Vatavu [100,101] employed a set of rating scales to capture both positive (e.g., perceived efficiency) and negative (e.g., perceived confusion) aspects of distal haptics UX. In Section 4, we draw on this prior work to inform UX measures tailored to haptics and touchscreen input. Next, we introduce our conceptual framework for body-level distal haptics.

3 The Distal Haptics Continuum

Research into distal haptics UX for touchscreen input has been limited to a few body locations in close proximity to the touch point, a limitation that can be attributed to the absence of a comprehensive framework to structure design possibilities for distal haptics. To address this aspect, we introduce the Distal Haptics Continuum, a conceptual framework for distal-haptic touchscreen input, where body regions are structured according to (i) *Body Laterality* and (ii) *Proximity* to the on-screen touch point, two dimensions that manifestly emerged in our literature review:

- The *Body Laterality* dimension specifies the body side where distal feedback is delivered, with the hand used for touch input as the point of reference. For example, vibrations delivered via a smartphone to the upper arm [70] of the hand performing touch input are on the *same* side. Conversely, vibrations provided via a smartwatch to the non-dominant wrist [42] are on the *opposite* side. For the sake of simplicity, we integrate locations along the midsagittal axis, e.g., the spine [49] and central abdomen [30], on the *same* side.
- *Proximity* denotes the distance from the touch point to the body region where distal feedback is provided. We specify proximity within three highly distinctive zones—*hand*, *arm*, and *whole-body*. To streamline this approach, we use ranks, referred to as *distal levels*, within each zone. For example, finger regions gradually more distant from the tip, e.g., the middle phalanx, proximal phalanx, etc., receive increasingly higher distal levels. The finger adjacent to the one touching the screen receives a lower level than a more distant finger of the same hand. Under-the-finger haptics, delivered by the touchscreen, are attributed the lowest (zero) distal level.

Figure 2 illustrates the Distal Haptics Continuum by highlighting only those body regions examined in our experiments, presented in Sections 4 to 6, corresponding to the *hand*, *arm*, and *whole-body* zones, with attributed distal levels from 1 to 16. However, the continuum encompasses essentially the whole body and, since ranks denote relative rather than absolute distance, their utilization can be tailored to specific needs. For example, if a researcher targets just six hand regions for vibrotactile feedback, corresponding to each finger and the dorsal side, as in Luzhnica and Veas' [67] glove device, distal levels can be assigned as simple numbers from 1 to 6, as illustrated in the left part of Figure 2. If more subregions are targeted, such as on the same finger as explored by Seim et al. [91], the number of distal levels can be readily adjusted as necessary, e.g., numbers 1 to 3 for the fingertip, middle phalanx, and proximal phalanx of

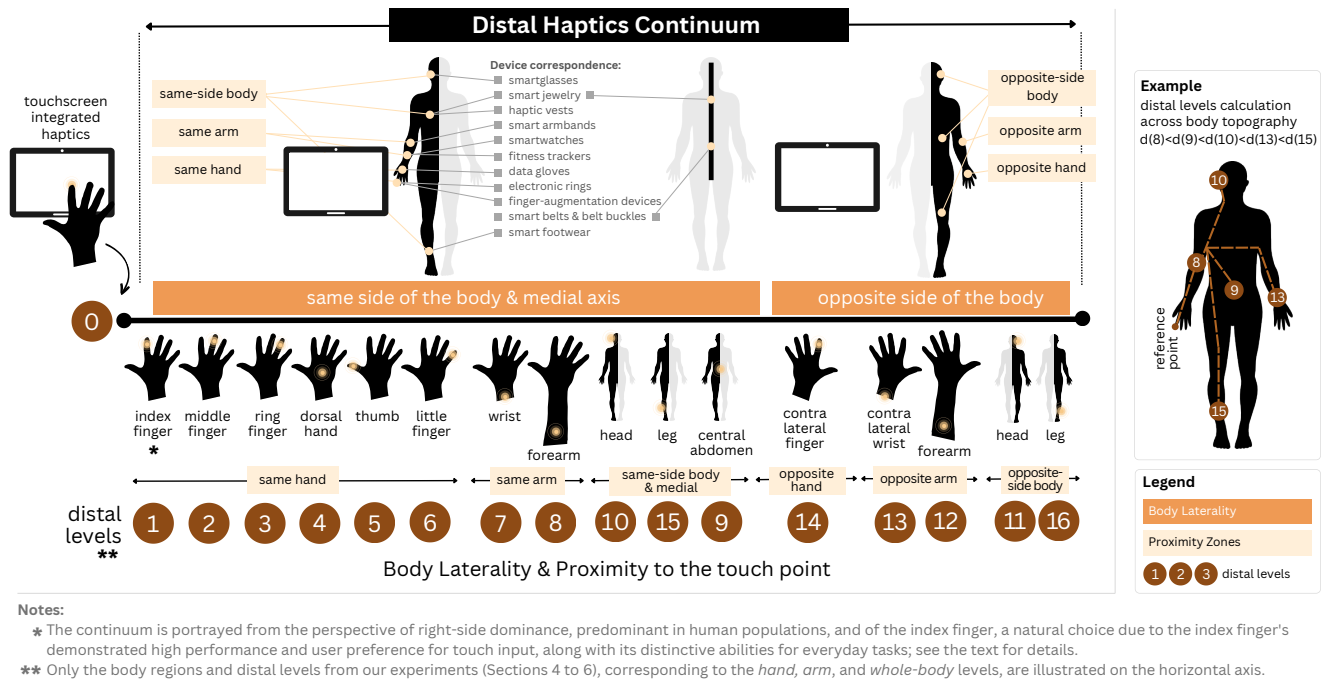


Figure 2: The Distal Haptics Continuum, structured according to *Body Laterality* and *Proximity* of body regions to the on-screen touch point. The continuum represents a flexible space—while it encompasses essentially the whole body, in this figure only those regions examined in our experiments are represented, which were attributed for this purpose distal levels from 1 to 16.

the index finger, after which the levels continue to increase for the adjacent fingers, dorsal side, wrist, and so forth. We determine distal levels as shortest-distance paths on the body’s topography, e.g., the distal level of the forearm on the same side is greater than that of the dorsal hand, but smaller than the level of the temple and central abdomen; see Figure 2, right for an illustration of this concept. The 16 distal levels in Figure 2, corresponding to the body regions examined in our experiments, were determined through anthropometric measurements on one subject. While we acknowledge variations in body size between individuals, we maintain that the resulting levels are sufficiently precise for our purpose and, furthermore, we were able to subsequently validate their relative order using Dijkstra’s [27] shortest path algorithm applied between vertices on an anatomically-accurate virtual human model.¹

The Distal Haptics Continuum is introduced as a flexible, rather than fixed, space that can be adapted to suit the designer’s specific needs. In this space, the *Body Laterality* and *Proximity* dimensions are used in conjunction to structure the relationship between the on-screen touch point and the on-body location where haptic feedback is presented. The particular representation we offer in Figure 2 is based on several key results from the scientific literature. For instance, body laterality refers to the conscious preference over the left or right sides of the body, which has genetic [113], developmental [24], and cultural [58] determinants. Given that left-handedness occurs in approximately 10% of the population [76], right-handedness is considered a universal human characteristic and, thus, we use it as the default representation in Figure 2—note,

¹<https://bodyvisualizer.com>

however, that adaptations for left-handed users are discussed in Section 7. Furthermore, prior research has shown that users prefer the index finger for reasons of comfort and speed [23], as well as perceived difficulty and success [63]. Noteworthy, 20 of the 25 high-consensus gestures (80%) for surface computing, unveiled by Wobbrock et al.’s [117] seminal study on touchscreen gesture elicitation, involve the index finger (p. 1089). Moreover, using different fingers leads to different touch input performance in terms of off-sets measured from the target center, touch time, centroid variation, and others [23,39,110]. For these reasons, the Digital Haptics Continuum is portrayed in Figure 2 from the perspective of the index finger, but Section 7 addresses adaptations to other fingers as well.

The Distal Haptics Continuum is meant to structure possibilities in distal haptics UX for body parts progressively farther from the touch point. The very nature of these experiences is the scope of our work. In Sections 4 to 6, we present three experiments conducted to unveil the distal haptics UX, implemented with vibrotactile feedback across the *hand*, *arm*, and *whole-body*, encompassing 16 distinct body regions increasingly farther from the touch point. Given the limited research on documenting the UX of distal haptics, as outlined in Section 2, we designed our experiments to be exploratory rather than hypothesis-driven [44]. This approach offered greater flexibility at this point, allowing us to analyze the UX of distal haptics through a discovery-oriented lens, rather than focusing on preregistered hypotheses [86]. Our guiding question for these experiments is how the unique qualities of distal haptics shape users’ experiences of touchscreen input, which we rigorously examine across various distal levels of the Distal Haptics Continuum.

4 Experiment #1: Touchscreen Input with Distal Haptics at the Hand Level

We conducted an experiment to obtain insights into the UX of vibrotactile feedback delivered during touch input at various locations on the *hand*, progressively more distal from the touch point.

4.1 Experiment Description

4.1.1 Participants. Fifteen people (eleven self-identified as male and four as female), aged between 18 and 44 years old ($M=26.2$, $SD=8.5$ years), were recruited via mailing lists and convenience sampling. All participants were regular smartphone users, with nine (60%) reporting the use of the keyboard vibration feature on their devices, ensuring a relevant demographic sample with diverse preferences and familiarity of smartphone vibrotactile feedback. Eight of the participants (53.3%) reported using smartwatches on a daily basis. All of the participants were right-handed.

4.1.2 Apparatus. To explore the UX of distal haptics, we developed a custom application for an interactive tabletop (Figure 3) and a custom wearable device equipped with multiple vibration motors (Figure 4). The application features an interactive map showcasing pins that represent diverse tourist attractions from cities around the world. When the user taps on a specific pin, a modal window opens, displaying a photograph and a brief description. Simultaneously, the wearable device delivers vibrations at a specific location on the user's hand, e.g., the index finger, thumb, or dorsal side; see Subsection 4.1.4 for the experimental conditions. We developed the map application using Leaflet,² and deployed it on a 46-inch Ideum Platform³ tabletop (1920×1080 pixels, 12 ms touch response time, Intel Core i7-4790S 3.2GHz CPU, 16GB RAM, Windows 8.1). The wearable device incorporates six 10 mm DC coin ERM vibration motors⁴ (11,000±2,500 rpm) that can be controlled individually via an Arduino Nano board following events received on the serial port from the map application signaling touch input. Based on the empirical results reported by Seim et al. [91] on user perception of vibrotactile stimuli at finger level, we opted for ERM over LRA motors due to the higher recognition accuracy they enabled. The motors were stably attached to the fingers and dorsal side of the hand using Velcro bands, as illustrated in Figure 4. Following prior studies [18,91,100,108],⁵ we implemented vibrotactile feedback as a 150ms-long pulse of maximum intensity, known to increase salience [49], corresponding to a nominal amplitude vibration strength of 1.4G for each motor, powered at 3V.

4.1.3 Task. After signing a consent form, the participants completed a demographic questionnaire. Subsequently, they were explained the task, consisting of touching the pins on the map to

access the corresponding hidden information and identify the earliest year among all tourist attractions; see Figure 3. Participants were instructed to use the index finger of their dominant hand for touch input, and encouraged to revisit the pins for as many times as they wished to assist refreshing their memory and ensure the accuracy of their responses. While we asked them to focus on the primary objective of identifying the earliest year, the underlying purpose was to provide sufficient time to engage with distal haptics.

The primary requirements of our task, which involved presenting visual information on a touchscreen with confirmatory haptic feedback following touch input, were (i) use of visual attention to locate specific targets, (ii) visuomotor coordination to touch and select targets, and (iii) perception of vibrotactile stimuli delivered at various on-body locations. The interactive map application fulfilled requirements (i) and (ii), while our experimental conditions grounded in findings from the literature on user perception (Subsection 2.1) laid the foundation for requirement (iii) through our versatile wearable device. The specific UX measures outlined in Subsection 4.1.4 were deliberately chosen to capture the various nuances of this generic touch input task in the presence of distal haptics. A training session, represented by one city map with fifteen pins, was used for familiarization with our setup.

The actual experiment contained seven maps corresponding to seven conditions of distal feedback at various locations on the hand, e.g., index finger, thumb, etc.; see Subsection 4.1.4 for details. Each participant experienced all conditions, which were presented in a randomized order. At the end, participants completed a questionnaire with UX measures designed to capture their experience of touchscreen input accompanied by distal haptics at *hand* level. On average, the experiment lasted 45 minutes per participant, and the participants performed a total of 18,745 touches.

4.1.4 Design and measures. Our experiment followed a within-subjects design with one independent variable, LOCATION, which comprised seven conditions: *index finger*, *middle finger*, *ring finger*, *little finger*, *thumb*, *dorsal hand*, and *none*. The latter served as an explicit control, absent in prior work [100,101]. The motors were positioned at the midpoint of the middle phalanges [31,67,100], the distal phalanx for the thumb [67], and at a one-third distance from the wrist along the imaginary line connecting the wrist and middle finger for the dorsal side of the hand, following [14,17]. These placements ensured that the fingertips remained unobstructed for touch input while minimizing gripping interference. Furthermore, these regions can be easily targeted using off-the-shelf wearables, such as rings and gloves. For each condition, we evaluated:

- PREFERENCE, an overall rating of the experience of distal vibrotactile feedback, assessed using a 7-point Likert scale with items from 1 (lowest preference) to 7 (highest preference).
- UMUX (Usability Metric for User Experience) [34], a qualitative assessment of usability in terms of perceived effectiveness, efficiency, and satisfaction, between 0 (low) and 100 (high). UMUX is the short alternative of the established SUS [16], quicker to administer in four questions only [64].
- Following [100,101], we evaluated specific aspects of the perceived experience of distal vibrotactile feedback accompanying touch input using 7-point Likert ratings ranging from 1 (strongly disagree) to 7 (strongly agree): ENJOYMENT

²Leaflet is a popular and powerful JavaScript library for dynamic, visually engaging maps, <https://leafletjs.com>.

³<https://www.ideum.com/products/touch-tables>

⁴<https://nfpshop.com/product/10mm-coin-vibration-motor-3mm-type-model-nfp-c1030>

⁵Results from [108] revealed that ERM vibration motors require between 110-120ms to reach full amplitude. Furthermore, evaluations from [91] showed no statistically significant difference between 150 ms and longer activation duration on users' discrimination performance of vibrotactile patterns. Other studies [18,100] used 150 ms-long vibrations as well or informed the duration of vibrotactile stimuli around this value, based on such considerations [26].

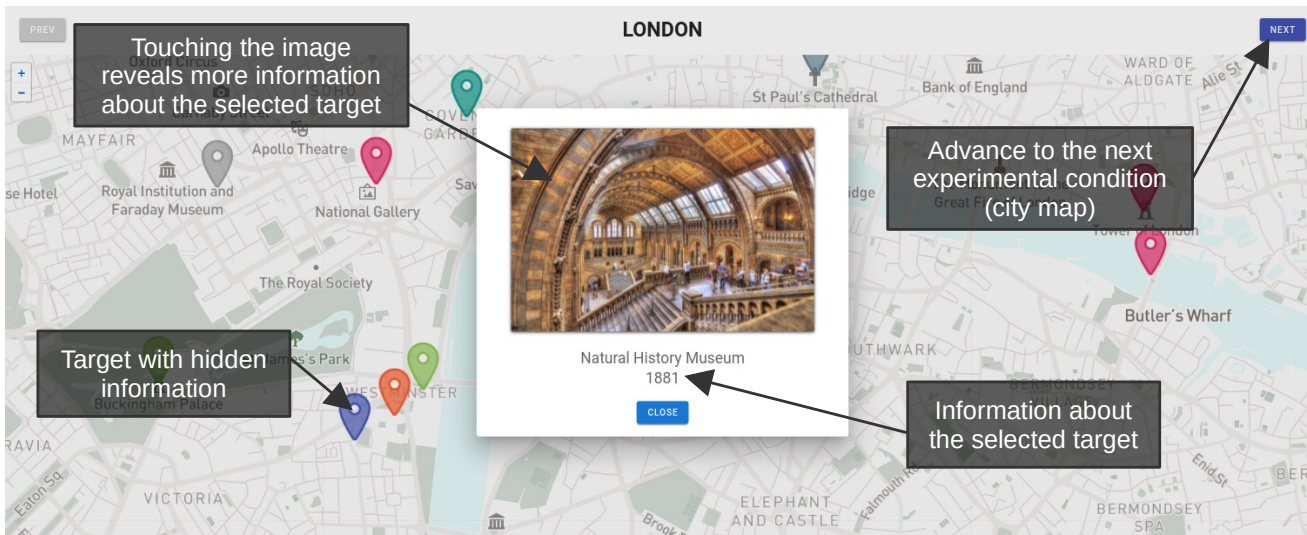


Figure 3: The interactive map application running on the touchscreen tabletop with the goal to engage participants in touching highlighted targets to discover hidden information. Each touch was accompanied by vibrotactile feedback on the body. Different city maps were provided for various experimental conditions, such as feedback on the index finger or the thumb.

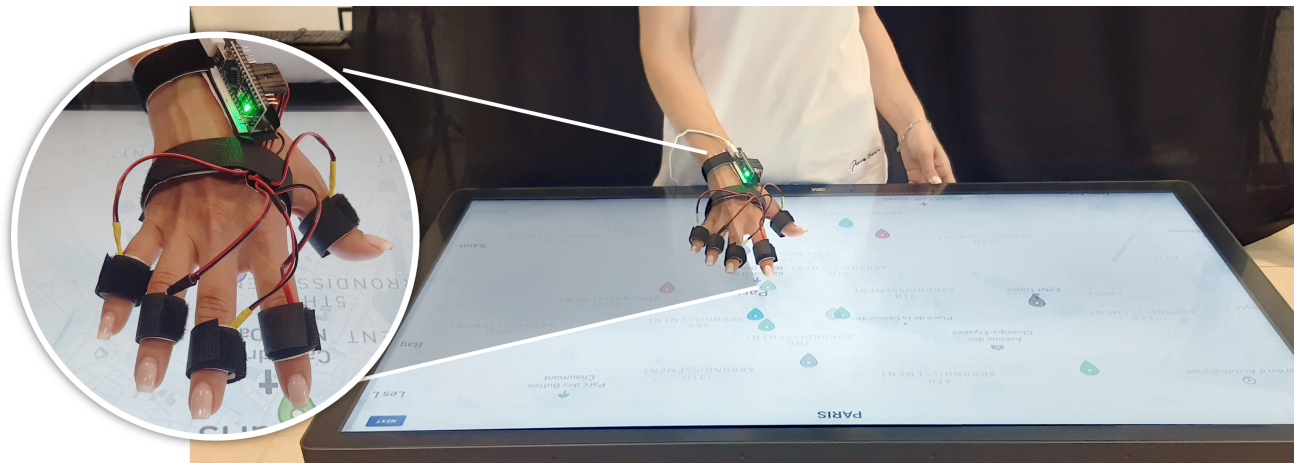


Figure 4: A close-up of the custom wearable device used for examining distal haptics UX at *hand* level in our first experiment.

in response to the statement “Interacting with the touchscreen felt enjoyable”; EFFICIENCY, “Interacting with the touchscreen felt efficient”; CONFIDENCE, “Interacting with the touchscreen felt confident”; SUITABILITY, “Interacting with the touchscreen felt appropriate”; DISTRACTEDNESS, “Interacting with the touchscreen felt distracting”; DIFFICULTY, “Interacting with the touchscreen felt difficult”; CONFUSION, “Interacting with the touchscreen felt confusing”; COMPLEXITY, “Interacting with the touchscreen felt complex.” This set of measures was purposefully crafted to include an equal number of words with positive and negative connotations, e.g., “efficient” vs. “difficult,” to capture the multifaceted distal haptics UX related to perceived usability, affect, trust, value, workload [95] as well as usability requirements and

experiential dimensions [95]. For example, ENJOYMENT and EFFICIENCY represent short-term affective response and instrumental UX qualities [59], respectively, while the negatively connoted DISTRACTEDNESS and DIFFICULTY serve as contrasts. Furthermore, the opposite pairs of CONFIDENCE and CONFUSION, along with SUITABILITY and COMPLEXITY, address the experience of confirmatory haptic response following on-screen touch input in relation to UX aspects of harmony and involvement [5]. Overall, this set offers a rich perspective on the UX of distal haptics, capturing both affective and utilitarian nuances revealed through the duality of positively and negatively connoted terms.

- We aggregated individual ratings from this set into a comprehensive measure, the Distal Haptics User Experience

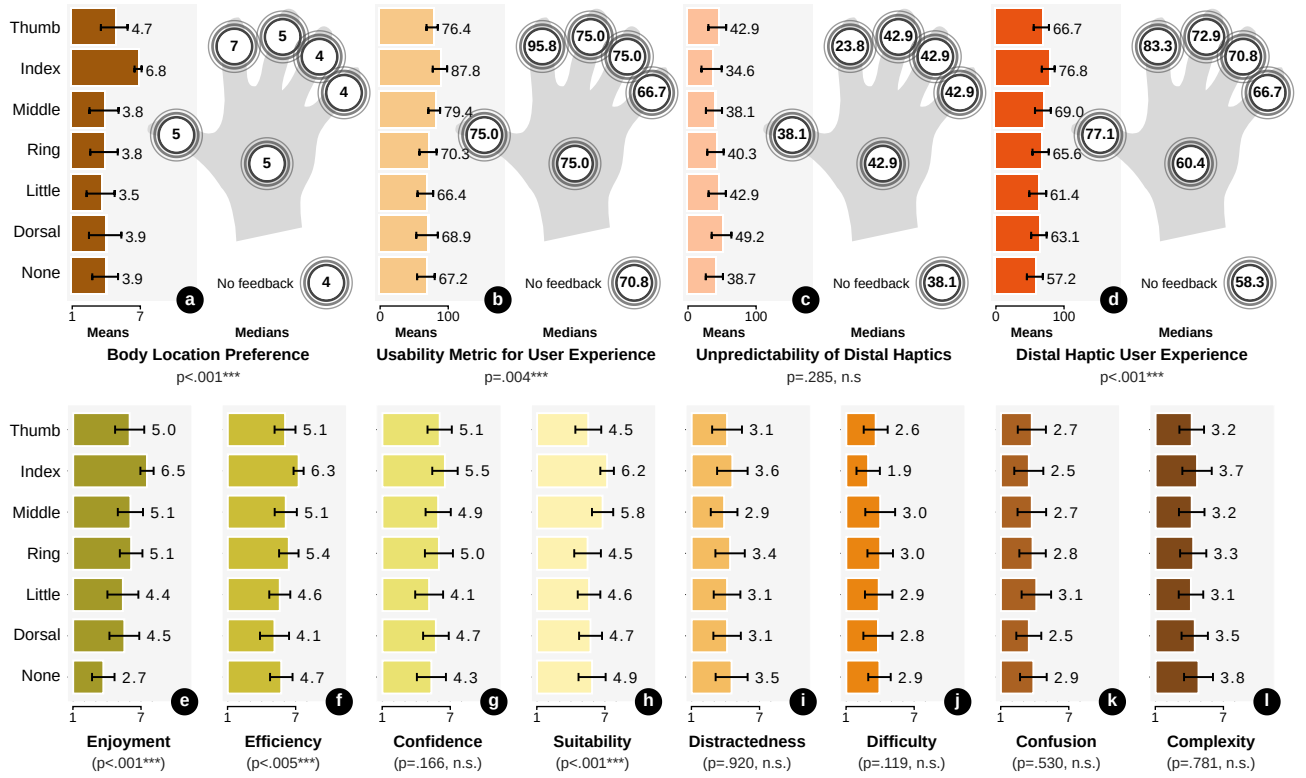


Figure 5: The UX of distal vibrotactile feedback delivered at various body locations at the *hand* level. Note: the bar charts report means with 95% CIs, while medians are also presented in the top figures within the circles positioned at each body location.

(DHUX), to quantify this multifaceted experience. We computed DHUX in a manner similar to the scoring systems used in SUS [16] and UMUX [34] by summing up the ratings of positively connoted items and the complementary values with respect to 7 of the negatively connoted ones. The score was normalized in [0..100]:

$$\text{DHUX} = \frac{((\text{ENJOYMENT} - 1) + (7 - \text{DISTRACTEDNESS}) + (\text{EFFICIENCY} - 1) + (7 - \text{DIFFICULTY}) + (\text{CONFIDENCE} - 1) + (7 - \text{CONFUSION}) + (\text{SUITABILITY} - 1) + (7 - \text{COMPLEXITY})) \cdot \frac{100}{8 \cdot 6}}{8 \cdot 6} \quad (1)$$

- We measured the UNPREDICTABILITY of distal haptics using items Q₆, Q₇, and Q₈ of the Perceived Creepiness of Technology Scale [119], which account for negative feelings of users not being able to anticipate system actions.

4.1.5 Statistical analysis. We use medians (Mdn) as the preferred indicator of central tendency for Likert-scale measures, such as ENJOYMENT or DISTRACTEDNESS, but also report means (M) for a broader perspective on the data. We employ ANOVA with the Aligned-Rank Transform (ART) for nonparametric factorial data analysis, provided by ARTool [116], partial eta squared η_p^2 for effect sizes, and use False Discovery Rate (FDR) adjustments [10] for p -values during post-hoc multiple comparisons contrast tests implemented with the ART-C algorithm [29].

4.2 Results

4.2.1 Preferred locations for distal haptics. We found a significant effect of LOCATION on PREFERENCE ($F_{(6,84)}=6.373$, $p<.001$, $\eta_p^2=.31$), revealing the *index finger* as the most preferred location at the *hand* level for distal vibrotactile feedback during touchscreen input (Mdn=7 and M=6.8 on a 1 to 7 scale), significantly more preferred than all of the other locations evaluated in our experiment ($p<.005$, FDR p -value adjustments applied); see Figure 5a. The *thumb* garnered the second-highest preference (Mdn=5, M=4.7), yet significantly lower ($p=.003$) than the *index finger*. As for the remaining conditions of LOCATION, including the absence of vibrotactile feedback, they received notably lower average ratings, ranging from 3.5 to 3.9. The *little finger*, situated at the farthest distance from the touch point, received the lowest rating (Mdn=4, M=3.5) but, interestingly, there was no significant difference between our participants' preference for the *little finger* and the control condition of no vibrotactile feedback (Mdn=4, M=3.9, $p=.811$, $n.s.$).

4.2.2 The UX of distal haptics during touchscreen input. The preference ratings were confirmed by the UMUX scores with a significant effect of LOCATION ($F_{(6,84)}=3.430$, $p<.005$, $\eta_p^2=.20$) and the highest preference for the *index finger* (Mdn=95.8, M=87.8 on a 0 to 100 scale); see Figure 5b. Post-hoc contrast tests revealed significant differences between the *index finger* and the *ring finger*, *little finger*, *dorsal hand*, and *none* ($p<.05$), but not the *middle finger* (Mdn=75,

$M=79.4$, $p=.218$, $n.s.$) or the *thumb* ($Mdn=75$, $M=76.4$, $p=.074$, $n.s.$), which were the second and third-highest scoring locations. The least usability was attributed to *little finger* and *none* ($p=.687$, $n.s.$).

We did not detect a significant effect of LOCATION on UNPREDICTABILITY ($F_{(6,84)}=1.260$, $p=.285$, $n.s.$), with mean scores ranging between 23.7 (*index finger*) to 40.7 (*dorsal hand*), where lower values indicate better results; see Figure 5c. However, we found a significant effect of LOCATION on DHUX ($F_{(6,84)}=4.385$, $p<.001$, $\eta_p^2=.24$), our multifaceted measure of distal haptics UX; see Figure 5d. The highest score was attributed to the *index finger* ($Mdn=83.3$, $M=76.8$ on a 0 to 100 scale), significantly higher than the *thumb*, *ring finger*, *little finger*, *dorsal hand*, and *none* ($p<.05$), but not the *middle finger* ($Mdn=72.9$, $M=69.0$, $p=.105$, $n.s.$), which was again the second-highest rated location. The control condition of no vibrotactile feedback received the lowest score ($Mdn=58.3$, $M=57.2$), significantly lower compared to both the *index finger* ($p<.001$) and *middle finger* ($p=.041$). To understand these results more closely, we looked at the constituent measures of DHUX; see Figures 5e to 5l. We found that the *index finger* scored the best across six of these measures, except for DISTRACTEDNESS and COMPLEXITY, for which we did not find significant effects of LOCATION ($p>.05$, $n.s.$). We detected however significant effects on perceived ENJOYMENT ($F_{(6,84)}=5.858$, $p<.001$), EFFICIENCY ($F_{(6,84)}=4.016$, $p<.005$), and SUITABILITY ($F_{(6,84)}=4.437$, $p<.001$) with large effect sizes ($\eta_p^2=.29$, $.22$, and $.24$).

4.3 Takeaways

Our experiment revealed a clear preference for distal haptics over no haptics at all in touchscreen input, despite the spatial decoupling from the touch point. With new UX measures and the explicit control condition of no haptic feedback, which was missing in [100,101], our findings about the *index finger* reinforce with greater rigor those from prior work. Moreover, by expanding our scope to include five additional hand regions beyond [100,101], we revealed that the adjacent fingers, namely the *middle finger* and *thumb*, received notably high UX scores. These findings complement with UX insights results on localizing vibrations at the finger level [67,91] and indicate new possibilities for interaction techniques incorporating distal haptics on these fingers, a topic we explore in detail in Section 7. In contrast, vibrations delivered to the *dorsal hand* received much lower UX scores, highlighting the limited effectiveness of this region for distal haptics in touchscreen input, despite its close proximity to the touch point and prevalence in data gloves.

5 Experiment #2: Touchscreen Input with Distal Haptics at the Arms Level

For more insights into the UX of distal haptics for touchscreen input, we conducted a subsequent experiment involving the *wrist* and *forearm*, two locations progressively more distant from the touch point compared to those in our first experiment. Moreover, we extended our examination of distal haptics on the *opposite* arm as well. Our interest in these locations is driven by commonly available off-the-shelf wearables, such as smartwatches and armbands.

5.1 Experiment Description

5.1.1 Participants. Fifteen people (eleven self-identified as male and four as female), aged between 22 and 44 years ($M=28.5$, $SD=8.0$

years), were recruited via mailing lists and convenience sampling. None of the participants took part in our first experiment. Except for one, all of the participants were regular smartphone users with eight (53.3%) reporting the use of the keyboard vibration feature on their devices, ensuring a relevant demographic sample with diverse preferences and familiarity of smartphone vibrotactile feedback. Seven participants (46.7%) also reported using smartwatches or fitness trackers and five (33.3%) smart earbuds on a daily basis. All of the participants were right-handed.

5.1.2 Apparatus, task, design, and measures. We employed the same apparatus, task, within-subjects design, and measures as in our first experiment; see Section 4 for details. However, the independent variable LOCATION featured the following seven new conditions: *index finger*, *opposite index finger*, *wrist*, *opposite wrist*, *forearm*, *opposite forearm*, and *none* (the control condition), where “opposite” refers to the side of the body contralateral to the hand used for touch input, according to the *Body Laterality* dimension of our Distal Haptics Continuum (Figure 2). We maintained the same placement of vibration motors on the *index finger* as in the first experiment. For the other regions, we positioned the motors at the midsection of the dorsal side of the *wrist* [42,96] and on the dorsal forearm at 4 cm from the elbow [84]. We slightly adapted our wearable device to conveniently and stably position the motors at these locations; see Figure 6. Each participant experienced all conditions, which were presented in a randomized order.

5.2 Results

5.2.1 Preferred locations for distal haptics. We detected a significant effect of LOCATION on PREFERENCE ($F_{(6,84)}=2.454$, $p=.031$, $\eta_p^2=.15$), and post-hoc contrasts (FDR corrections for p -values) revealed significant differences between *index finger* and *none* ($p=.016$) and *wrist* and *none* ($p=.049$), respectively; see Figure 7a. The control condition, representing no vibrotactile feedback, was attributed the lowest preference rating ($Mdn=2$, $M=2.9$), whereas all the other conditions received median ratings above 3 and means above the midpoint of the 7-point scale, ranging from 3.9 to 5.3. The *wrist* ($Mdn=5$, $M=4.9$) and *forearm* ($Mdn=4$, $M=4.4$) on the same side as the hand used for touch input were scored similarly to the *index finger* ($Mdn=6$, $M=5.3$), but also closely to their counterparts, the *opposite wrist* ($Mdn=4$, $M=4.2$) and *opposite forearm* ($Mdn=4$, $M=3.9$), with no statistically significant differences ($p>.05$, $n.s.$).

5.2.2 The UX of distal haptics during touchscreen input. There was no significant effect of LOCATION on UMUX ($F_{(6,84)}=1.232$, $p=.298$, $n.s.$) or UNPREDICTABILITY ($F_{(6,84)}=1.767$, $p=.116$, $n.s.$); see Figures 7b and 7c. However, we found a significant effect on DHUX ($F_{(6,84)}=2.343$, $p=.038$, $\eta_p^2=.14$), revealing participants’ preferences for the *index finger* ($Mdn=81.2$, $M=74.4$), which was rated significantly higher than *none* ($Mdn=52.1$, $M=55.6$, $p=.044$); see Figure 7d. An in-depth look at the constituent measures of DHUX—Figures 7e to 7l—showed significant effects of LOCATION on EFFICIENCY ($F_{(6,84)}=3.287$, $p=.006$, $\eta_p^2=.19$), CONFIDENCE ($F_{(6,84)}=2.705$, $p=.019$, $\eta_p^2=.16$), and SUITABILITY ($F_{(6,84)}=4.163$, $p=.001$, $\eta_p^2=.23$) with significant differences between the *index finger* and *none* (p -values $<.009$, FDR adjustments applied). Additionally, we found that the *wrist* was perceived as more suitable ($Mdn=5$, $M=5.1$) over *none* ($Mdn=3$, $M=3.3$,

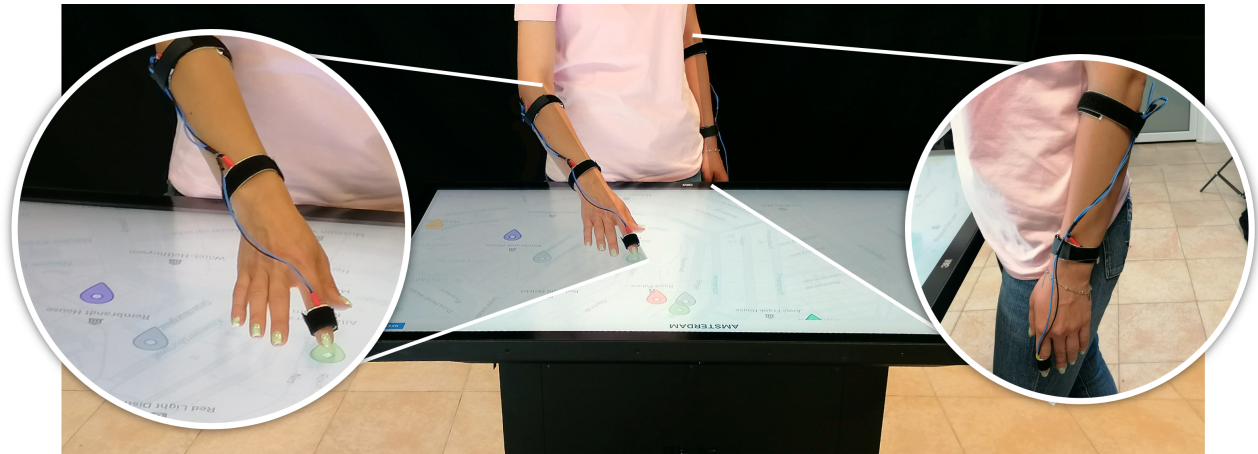


Figure 6: A close-up of the apparatus used for examining distal haptics UX at *arms* level in our second experiment.

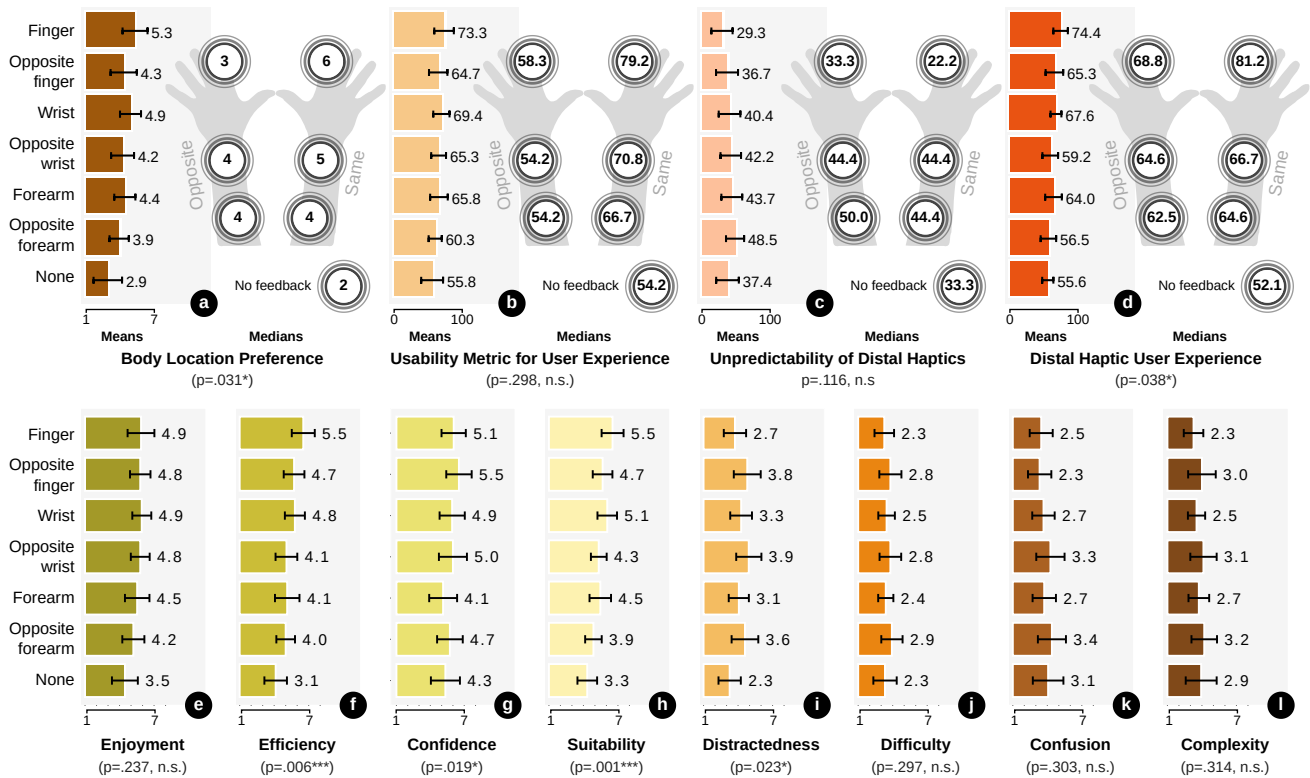


Figure 7: The UX of distal vibrotactile feedback delivered at various body locations at the *arms* level. *Note*: the bar charts report means with 95% CIs, while medians are also presented in the top figures within the circles positioned at each body location.

$p=.010$). In contrast to our first experiment, we detected a statistically significant effect of LOCATION on a UX measure designed to evaluate the negatively connoted experience of DISTRACTEDNESS ($F_{(6,84)}=2.611, p=.023, \eta_p^2=.16$), with significant differences between the *opposite index finger* and *none* (3.8 vs. 2.3, $p=.038$) and the *opposite wrist* and *none* (3.9 vs. 2.3, $p=.034$).

5.3 Takeaways

Our second experiment provided additional insights into the UX of distal haptics applied farther from the touch point, expanding on prior work [100,101] with several new body regions at the *arm* level. With new UX measures and an explicit control condition, we consolidated previous findings regarding the *wrist* and *forearm*,

which closely followed the *index finger* in terms of UX. Moreover, with a larger scope than in prior work, we discovered that corresponding locations on the *opposite* side received high ratings for enjoyment, efficiency, confidence, and suitability, outperforming the control condition of no vibrations despite their increased spatial decoupling from the touch point. These findings offer new insights, from the UX perspective, into the relationship between localization accuracy and tactile sensitivity in feedback across both arms [25] and indicate opportunities to leverage the *opposite* arm in interaction techniques involving secondary feedback that complements the primary one delivered on the *same* side. We explore these findings further in Section 7, where we propose future research opportunities on arm-level distal haptics for touchscreen input.

6 Experiment #3: Touchscreen Input with Distal Haptics at the Whole-Body Level

The previous two experiments revealed that changes in the UX exhibit specific nuances as we move away from the on-screen touch point. To gain even more insights, we conducted a third experiment, expanding our focus to the *whole body*. Our interest for locations at the *feet*, *abdomen*, and *head* level is driven by the availability of off-the-shelf wearables, such as smartglasses, footwear, and haptic vests, capable of providing vibrotactile feedback across the body.

6.1 Experiment Description

6.1.1 Participants. Fifteen people (twelve self-identified as male and three as female), aged between 20 and 34 years ($M=24.6$, $SD=4.1$ years), were recruited via mailing lists and convenience sampling. None of the participants took part in our previous two experiments. All of the participants were regular smartphone users with nine (60.0%) reporting the use of the keyboard vibration feature on their devices, ensuring a relevant demographic sample with diverse preferences and familiarity of smartphone vibrotactile feedback. Eight participants (53.3%) reported using smartwatches and four (26.7%) reporting using smart earbuds on a daily basis. Except one, all of the participants were right-handed.

6.1.2 Apparatus, task, design, and measures. We used the same apparatus, task, design, and measures as in our previous two experiments, but the independent variable LOCATION featured the following seven new conditions: *index finger*, *opposite temple*, *temple*, *abdomen*, *opposite foot*, *foot*, and *none*. We kept the same placement of the vibration motor on the *index finger* as in the first two experiments. The other motors were placed on the *temples* using a pair of protection glasses [74], above the ankle at the lower end of the peroneus longus muscle [72], and at the midsection of the waist, following [33,80]. We also slightly adapted our wearable device to stably position the motors at these locations; see Figure 8 for a photograph captured during the experiment. Each participant experienced all conditions, presented in a randomized order.

6.2 Results

6.2.1 Preferred locations for distal haptics. We found a significant effect of LOCATION on PREFERENCE ($F_{(6,84)}=4.004$, $p<.001$, $\eta_p^2=.22$) and significant differences between the *index finger* ($Mdn=7$, $M=6.2$) and all of the other conditions ($p<.05$, FDR corrections) except for

the *abdomen* ($Mdn=6$, $M=4.7$, $p=.083$, *n.s.*). The lowest ratings were attributed to the *temples*, either on the *same* side ($Mdn=3$, $M=3.5$) or the *opposite* side ($Mdn=2$, $M=3.3$) of the body, respectively.

6.2.2 The UX of distal haptics during touchscreen input. The preference results were confirmed by a statistically significant effect of LOCATION on UMUX ($F_{(6,84)}=6.435$, $p<.001$, $\eta_p^2=.31$). Post-hoc contrasts unveiled significant differences between the *index finger* ($Mdn=91.7$, $M=87.2$) and all other conditions ($p<.05$), except *none* ($Mdn=87.5$, $M=76.9$, $p=.238$), which ranked second. This finding highlights that distal feedback delivered too far from the touch point is perceived as little usable. Both the conditions of no vibrations and vibrations at the *feet* level were rated higher than the *temples* ($p=.048$ and $p=.002$), with the latter receiving the lowest UMUX scores ($M=52.8$ and 50.6) among all examined conditions.

Unlike in the first two experiments, we found a significant effect of LOCATION on UNPREDICTABILITY ($F_{(6,84)}=6.938$, $p<.001$, $\eta_p^2=.33$). Post-hoc contrasts revealed significant differences ($p<.05$) between the *index finger* ($M=10.0$) and all other conditions, except for *none*, and between *none* ($M=21.5$) and all other body regions, except for the *abdomen* ($M=35.2$). The latter ranked third in participants' preferences; see Figure 9c. These findings complement our earlier results, highlighting the *temples* as the most unpredictable regions for delivering distal haptics during touchscreen input.

We detected a significant effect of LOCATION on DHUX ($F_{(6,84)}=5.240$, $p<.001$, $\eta_p^2=.27$), with the *temples* consistently rated lower than the *index finger*, *abdomen*, and *none* ($p<.05$) and garnered the lowest scores ($M=58.1$ and $M=54.7$)—a 30% decrease from the highest score of 85.0 attributed to the *index finger*. In contrast, the *feet* were rated reasonably high ($M=70.4$ and 68.1), following the *abdomen* ($M=72.1$). An in-depth analysis of DHUX revealed significant effects of LOCATION on the positively connoted dimensions of ENJOYMENT ($F_{(6,84)}=5.992$, $p<.001$, $\eta_p^2=.30$), EFFICIENCY ($F_{(6,84)}=5.236$, $p<.001$, $\eta_p^2=.27$), CONFIDENCE ($F_{(6,84)}=4.088$, $p=.001$, $\eta_p^2=.23$), and SUITABILITY ($F_{(6,84)}=3.648$, $p=.003$, $\eta_p^2=.21$). In contrast to our previous two experiments, we detected significant effects of LOCATION across all negatively connoted UX measures. For example, *none* scored significantly lower ($Mdn=1.0$, $M=1.3$) than all other conditions ($p<.05$) across DISTRACTEDNESS ($F_{(6,84)}=7.498$, $p<.001$, $\eta_p^2=.35$), with the *temples* being perceived as more distracting than the *index finger* and *foot* ($p<.05$). A significant effect of LOCATION on DIFFICULTY ($F_{(6,84)}=3.485$, $p=.004$, $\eta_p^2=.20$) indicated that vibrations on the *temples* were perceived as more challenging compared to vibrations on the *index finger* ($p=.010$) and no vibrations at all ($p<.026$). Furthermore, a significant effect on CONFUSION ($F_{(6,84)}=2.521$, $p=.027$, $\eta_p^2=.15$) revealed vibrations on the *opposite temple* more confusing compared to the *index finger* ($p=.024$).

6.3 Takeaways

The third experiment broadened our understanding of distal haptics UX across various regions at the *whole-body* level, not explored in prior work [100,101], revealing some intriguing nuances. Notably, the *temples* received the lowest UX scores, restricting the use of vibrotactile feedback, already integrated in many smartglasses models, for touchscreen input. The *feet* and *abdomen* earned relatively high UX scores, suggesting promising opportunities for interaction

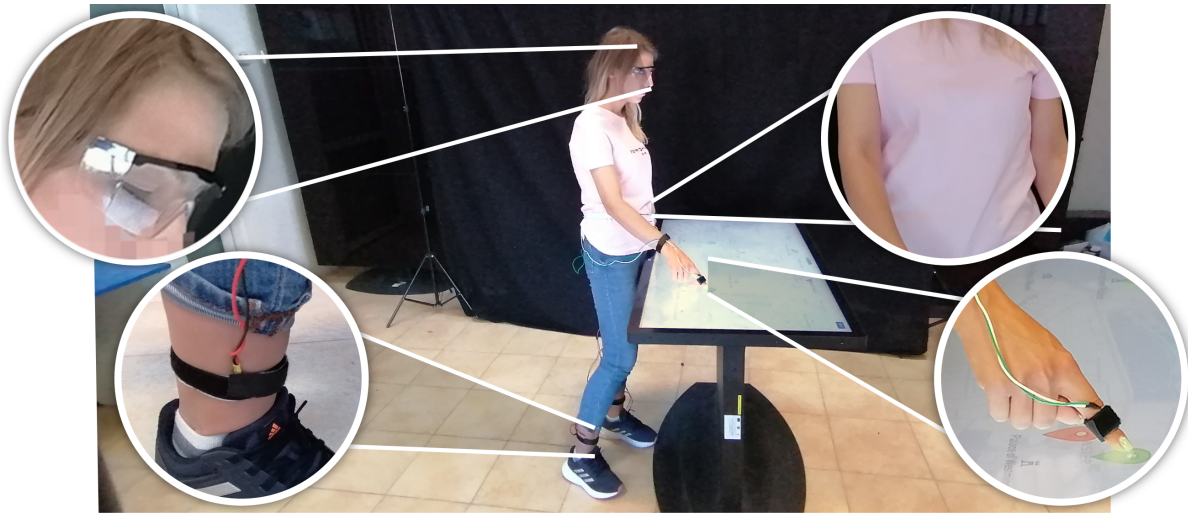


Figure 8: A close-up of the apparatus used for examining distal haptics UX at whole-body level in our third experiment. Note: the vibration actuator at the abdomen location is not visible in this photograph as it is placed on the skin, under the shirt.

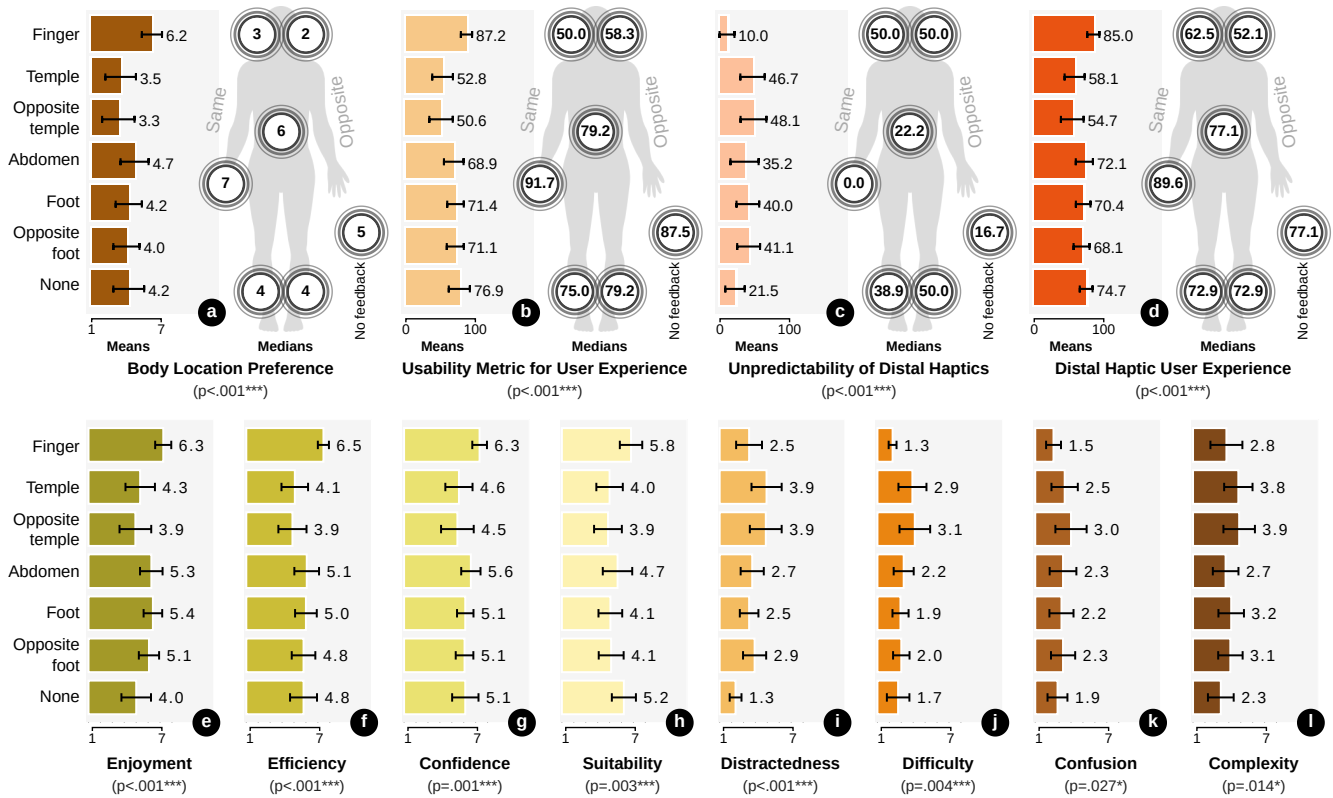


Figure 9: The UX of distal vibrotactile feedback delivered at various locations at the whole-body level. Note: the bar charts report means with 95% CIs, while medians are also presented in the top figures within the circles positioned at each body location.

techniques involving haptics at these locations, despite their lower sensitivity compared to other body regions [49]. The *abdomen*, in particular, known for its high information transfer rate [54], has

proven to be a valuable complement in terms of evoked UX to prior user perception findings in the literature. We discuss these opportunities in greater detail in the next section.

7 Discussion

We leverage our findings to offer future work opportunities for enhancing touchscreen interactions through distal haptics, which we exemplify with several use case scenarios. We propose adaptations of the Distal Haptics Continuum for diverse research needs.

7.1 It’s an Index-Finger World: What Next for Index-Finger Distal Haptics?

Our experiments consistently showed that users prefer distal haptic feedback on the index finger, which received the highest UX scores among all examined body regions. This finding aligns with the common use of the index finger in daily tasks due to its unique motor skills [47] and relationship with visual attention [19], respectively. At this level, we recommend:

- ❶ **Expand investigations into index-finger distal haptics with more informative vibration patterns.** The high DHUX ratings for the index finger—76.8, 74.4, and 85.0 at the *hand*, *arms*, and *whole-body* levels (Figures 5, 7, and 9)—reveal it as the most appropriate region for distal haptics. Our experiments used basic on/off pulses, but we anticipate richer feedback, featuring more complex vibration patterns, to further enhance UX. This may include vibrations with functional and affective characteristics [90], emotional connotations [2], or evoking plausible sensations of physical events [78] and physical buttons [55], towards more expressive interactions, conveying more than just touch confirmation. For example, in a file manager, a single-pulse vibration could indicate a folder containing few items, whereas a repeated pulse a folder with more files. Also, different file types could be represented by distinct vibration patterns, e.g., a long pulse followed by a short one for videos or a rhythmic pattern for music files [104]. To enhance touch typing, tactile feedback was recommended to mimic a physical keyboard [56], for which distal haptics on the index finger could simulate the texture of a physical key before it is pressed, while a different, more intense vibration could indicate the act of pressing.
- ❷ **Explore distal haptics integration with other modalities localized at the index finger.** The strong preference for index-finger output suggests that other modalities, delivered at the same location, might also be well-received. For instance, various finger-augmentation devices [94,103] already offer diverse output channels, e.g., visual output with nail displays [98], audio via rings [46], or pressure and stretch sensations on the skin [73]. Future work could explore combining these channels to create multimodal feedback distal from the touch point. Investigating this direction can potentially lead to enhanced touchscreen UX, but also inspire new wearable designs [102], including with finger gesture input capabilities [93], for use in conjunction with touchscreens.

While these directions represent exciting future work, they remain focused on the index finger, with feedback in the immediate vicinity of the touch point. However, we believe that the untapped potential of distal haptics emerges at greater distance from this point. Next, we expand on opportunities that extend beyond the index finger.

7.2 The Adjacent Fingers and Full Arm Offer Unique Opportunities for Distal Haptics

Besides the index finger, several body regions on the *hand* and *arm* received high UX ratings. At the *hand* level, the middle finger and thumb ranked second and third in both DHUX (69.0 and 66.7) and UMUX (79.4 and 76.4) ratings, indicating that fingers adjacent to the one used for touch input are also highly suitable for distal haptics. More distant fingers, such as the ring and little finger, which received lower DHUX (65.6 and 61.4) and UMUX (70.3 and 66.4) ratings, yet significantly higher than the control condition of no feedback, could also be harnessed for distal haptics in relation to their greater distance from the touch point. These insights inform several ideas for future explorations:

- ❸ **Explore interactions involving distal haptics on adjacent fingers.** Given the high user preference for the adjacent fingers, we recommend exploring interactions with output that involves them. For example, in a video game, tapping game elements with the index finger may trigger additional vibrations on the middle finger to signal life point collection or on the thumb to denote new weaponry acquired. Meanwhile, the index finger remains utilizable for mainstream output, as proposed in Subsection 7.1. Such explorations are grounded in prior findings on effective user perception of vibrations delivered to different fingers [67,91] and user preference for adjacent fingers used as output [92]. However, potential designs in this space must carefully consider the impact of masking [106] when vibrations are simultaneously delivered to closely spaced body regions, leading to confounding effects. Understanding the balance between localization clarity and the UX benefits of expanding vibrations across adjacent fingers towards new interactive experiences represents interesting experimental work, blending both user performance and user experience research.
- ❹ **Explore interactions involving distal haptics across multiple fingers.** Since the index finger was significantly preferred over the adjacent ones, the latter could be utilized to support and complement its feedback. This involves vibrations delivered onto multiple fingers reflecting fingers’ relative preference, e.g., vibrations fade away over to the adjacent fingers or migrate between fingers to complement on-screen visual cues. For example, when scrolling left and right with the index, vibrations could gradually spread to the middle and thumb fingers, signaling the scrolling direction and helping locate the content users are searching for.
- ❺ **Explore distal haptics where proximity to the touch point reflects information importance.** The ring and little finger, located at greater distance from the index, received lower yet still favorable UX ratings. This finding suggests using finger proximity to encode information importance, e.g., feedback on the index finger for critical information and on the little finger for less essential data. For example, in an interactive map application, feedback on the index finger could signal touching a crucial location, such as one with a high average daily temperature, whereas feedback on the little finger could denote secondary details, e.g., high wind speeds. Such interaction designs align with the use of

vibration stimuli for information encoding [31], and we recommend further investigations to explore the information transfer rate [54] through vibrations across both adjacent and distanced fingers, especially considering the potential masking effects observed at the hand level [106].

Going beyond the *hand* at the *arm* level, the wrist on the same hand ranked second in users' preferences, following the index finger. This finding recommends the smartwatch for implementing distal feedback [42,99], particularly for touchscreens lacking built-in haptics, and new opportunities for arm-level distal feedback:

- ⑥ **Explore distal haptics extending beyond the fingers to larger areas on the arm for enriched sensations.** This suggestion stems from the high ratings of the wrist and forearm in DHUX (67.6 and 64.0) and UMUX (69.4 and 65.8), indicating their potential to complement and extend finger-level feedback. For example, vibrations could start at the index finger and gradually extend to the wrist and forearm, covering users' top preferred body regions. In an action game, an explosion might trigger vibrations that propagate across all arm regions, intensifying the physical sensation and immersing the user more deeply in the game. In a time-sensitive task, the vibration's coverage could indicate remaining time: starting on the forearm, progressing to the wrist after a few seconds, and finally reaching the index finger as the deadline nears, in order to heighten user attention [112]. We believe that such designs could enable rich haptic experiences, but the information transfer rate [54] when delivering information across regions requires further examination. The challenge, to be addressed in future work, lies in balancing the richness of the felt experience with the clarity of the message conveyed through vibrations across regions with different tactile sensitivities and information transfer rates.

These directions can lead to new investigations into distal haptics involving various regions of the hand and arm beyond the index finger. Next, we offer recommendations involving distal haptics on the opposite side of the body.

7.3 Distal Haptics Playing on the Dichotomy of Opposite Body Sides

Our experiments unveiled interesting findings for distal haptics on the *opposite* side of the body compared to the hand used for implementing touch input. Even if locations on the same side consistently received higher DHUX and UMUX ratings than those on the opposite, they never reached statistical significance. Notable is the opposite index finger that received a high DHUX score (65.4), closely following the index finger (74.4) and wrist (67.6) of the same hand. In this context, the opposite side of the body could be leveraged for exploring innovative interactions that play on the connotations of the term "opposite," typically associated with contrast, contradiction, and negation, as follows:

- ⑦ **Leverage opposite sides for contrasting informational output.** In this direction, vibrations on the same side could confirm successful task completion, while vibrations on the opposite side could signal errors, alerts, or unexpected events.

For example, in a rhythm game where actions must synchronize with beats, when the user successfully performs a move, a vibration on the same hand might provide positive reinforcement for a correctly timed move, whereas a missed beat could trigger a vibration on the opposite hand as an alert.

- ⑧ **Leverage opposite sides for dichotomous choices.** Vibrations on contralateral sides, e.g., the left and right hands, can represent dichotomous choices, such as "right-left," "OK-cancel," or "yes-no." For example, when deciding to save or cancel a file modification, the horizontal arrangement of the two buttons could be complemented by vibrations delivered on the two hands, e.g., a pleasant vibration for "save" on the dominant hand and an erratic one for "cancel" on the non-dominant hand; see VibViz [90] for a library of vibration patterns with affective connotations. We recommend investigations into dual-side feedback for enhancing visual attention and decision-making confidence, potentially reducing the risk of inattentive touchscreen input.
- ⑨ **Explore interactions with haptics delivered through twin wearables.** Designing for distal haptics on both sides of the body opens up new possibilities for using twin wearables [52], such as rings or watches worn on each hand [22, 38]. For example, in an educational app, a ring on the dominant hand could provide feedback for correct answers, while a ring on the opposite hand feedback for incorrect ones, and both rings vibrating in pulsating mode could indicate a partially correct answer, giving the user another chance. We recommend such explorations, where user adoption of dual-side haptics could lead to new trends in wearables, beyond personal style and fashion associated to double-wristing [114], but for enhancing functionality in interactive systems.

These recommendations highlight opportunities for future work capitalizing on observed user preferences for contralateral body regions, with potential impacts on both interaction techniques and design of wearable devices. Next, we turn to those body regions that received the least preference, for which we equally highlight opportunities for further investigation.

7.4 Favor Distant Body Parts for Unexpected, Attention-Capturing Feedback

Even if none of the regions at the *whole-body* level yielded remarkable UX scores, our findings are valuable to recommend refraining from utilizing specific, low-scoring regions, such as the temples, for general feedback. Instead, we propose:

- ⑩ **Explore distant body parts for delivering crucial information through intrusiveness and unpredictability.** Our findings revealed the temples scoring the lowest in both DHUX (58.1 and 54.7) and UMUX (52.8 and 50.6), with the highest levels of unpredictability (46.7 and 48.1), distractiveness (3.9 and 3.9), and complexity (3.8 and 3.9) across all examined body regions. These traits suggest that their intrusiveness and unpredictability could be used to capture user attention effectively. For example, in a first-person shooter game, vibrations at the temples could signal crucial turns, catching user attention to avoid missing life-saving navigation cues. The feet received lower DHUX scores, yet higher

(70.4 and 68.1) than the temples, indicating potential for distal haptics, especially when the feet are used for input [105] through multitouch floors [7] or large displays [48]. Delivery of distal haptics at feet level could be implemented through dedicated haptic footwear [37], specific haptic devices—see Haptipedia [89]—or integrated into wearables and clothing through haptic enchanters [77].

Unlike our other recommendations from this section, which focused on positively rated aspects of distal haptics UX, the suggestion for incorporating distant body parts in future interaction techniques is based on how distal haptics could also harness the less favorable UX they evoke for further enhancing touchscreen interactions.

7.5 Extending the Distal Haptics Continuum

We introduced the Distal Haptics Continuum in Figure 2 as a framework for structuring distal haptics across the body, according to *Body Laterality* and *Proximity*. Our empirical findings substantiated the value of these theoretical dimensions. For example, *Body Laterality* offered interesting insights and new ideas for future distal haptics techniques. Concerning *Proximity*, a general rule of thumb is that the farther a body region is from the touch point, the less preferable it is for distal haptics. Significant correlations among the 16 distal levels depicted in Figure 2 and PREFERENCE ($r=-.721$, $p=.001$), UMUX ($r=-.615$, $p=.007$), and DHUX ($r=-.468$, $p=.050$) underscore the validity of this heuristic.

It is important to note that the continuum essentially applies for all body regions and, thus, can be used for just one body part, e.g., the hand, or otherwise extended as needed for other regions than those examined in our experiments. Furthermore, while we employed our continuum with a focus on right-handedness and the index finger, due to reasons provided in Section 3, its dimensions remain applicable for left-handedness as well when any other finger is used for input. The only alteration needed for reusing it in other contexts lies in recoding the distal levels representing proximity to the touch point. Also, our version of the Distal Haptics Continuum, originally simplified for practicality, can be further extended with new orthogonal dimensions, such as the complexity of vibrotactile stimuli, multitouch input involving combinations of fingers touching the screen, or specific aspects of haptic technology. We leave such interesting explorations for future work.

8 Limitations

There are a few limitations to our work, for which we propose strategies to address them in future research. First, our experiments focused exclusively on touch input performed with the index finger and implemented a generic task involving selecting targets sequentially, but we anticipate similar findings to be obtained for other fingers. However, distal haptics for more specific variations of touch input, such as scratching [41], crossing-based selection [66], pressure-based input [85] or user-defined gestures [107], might elicit different UX ratings and should be examined in dedicated follow-up investigations. Second, our sample consisted mostly of male participants, whereas female representation was lower (24%). Although we did not intend sex as an analysis factor, future work could examine potential sex differences in the perceived UX of distal haptics. Third, we worked with the hypothesis that touch input

is implemented using fingers and, in particular, with the index finger. However, not all users possess this motor ability, and previous work has unveiled numerous coping strategies adopted by people with upper-body motor impairments for interacting with touchscreen devices, e.g., by using their knuckles, feet, fist, or nose [4]. Although we did not address touchscreen input accessibility in this work, we expect the two dimensions of the Distal Haptics Continuum, *Body Laterality* and *Proximity*, to remain relevant for other body parts used for touch input. Interesting future work in this context involves adapting the Distal Haptics Continuum for different sensory sensitivities to detect vibrotactile stimuli, such as in users with various motor impairments experiencing tremor, spasm, or lack of sensation. In such cases, labeling body regions based on the shortest-distance paths on the body’s topography might be replaced by personalized mappings that leverage the actual sensitivity of those regions. Comparing the UX evoked by distal haptics for users with and without motor and sensory impairments may reveal new opportunities for designing accessible interactions, where touchscreen input is supported through distal haptics at specific on-body regions, according to user abilities and preferences.

Our experiments were exploratory in nature, rather than being driven by preregistered hypotheses, as our goal was to uncover insights into how distal haptics, delivered at specific regions, away from the touch point, or distributed across the body, contribute to the overall UX of touchscreen input. This open-ended approach yielded many empirical results and practical implications that lay the groundwork for future hypothesis-driven research to further understand the interplay between tactile sensitivity and user experience. Such future work, involving extension and generalization of our findings in new experiments with different user categories, body regions, and haptic technology could be readily conducted with off-the-shelf wearables, such as electronic rings, smartwatches, smartglasses, and haptic vests, since the body regions we addressed in our experiments are well covered by consumer devices. To this end, we make our dataset, comprising a total of 5,040 individual Likert-scale ratings collected from 45 participants, freely available at the web address <http://www.eed.usv.ro/~vatavu>.

9 Conclusion

We reported results from three experiments with 45 participants, conducted to unveil the UX of distal haptics across 16 body regions at the *hand*, *arm*, and *whole-body* levels, progressively farther from the on-screen touch point. This substantially expanded the scope of prior work by incorporating a variety of on-body locations, including those on the opposite side of the body from the hand implementing touch input. In this process, we leveraged the *Body Laterality* and *Proximity* dimensions of our newly introduced Distal Haptics Continuum, a space for structuring design possibilities in distal haptics across the whole body. Based on our findings, we strongly advocate for more research in this space for utilizing the body as a personal, always-available output medium during touchscreen interactions. This approach is particularly relevant for touchscreens lacking built-in haptics, for which we outlined new research opportunities. With the growing diversity and availability of wearable devices featuring haptic feedback, we look forward to novel interaction techniques aligned with these directions.

Acknowledgments

This work is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 860114. This work was also supported by a grant of the Ministry of Education and Research, CCCDI-UEFISCDI, project number PN-IV-P7-7.1-PTE-2024-0434, within PNCDI IV.

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