

Fingerhints: Understanding Users' Perceptions of and Preferences for On-Finger Kinesthetic Notifications

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Figure 1: We formalize on-finger kinesthetic feedback, e.g., conscious awareness of the hyper-extended state of the index finger (a), with “fingerhints,” a technology-agnostic descriptive language and design space. Our finger-augmentation device (b,c) leverages the mechanical force of a servomechanism to bypass user agency and deliver fingerhints, from subtle (b) to alert (c).

ABSTRACT

We present “fingerhints,” on-finger kinesthetic feedback represented by hyper-extension movements of the index finger, bypassing user agency, for notifications delivery. To this end, we designed a custom-made finger-augmentation device, which leverages mechanical force to deliver fingerhints as programmable hyper-extensions of the index finger. We evaluate fingerhints with 21 participants, and report good usability, low technology creepiness, and moderate to high social acceptability. In a second study with 11 new participants, we evaluate the wearable comfort of our fingerhints device against four commercial finger- and hand-augmentation devices. Finally, we present insights from the experience of one participant, who wore our device for eight hours during their daily life. We discuss the user experience of fingerhints in relation to our participants’ personality traits, finger dexterity levels, and general attitudes toward notifications, and present implications for interactive systems leveraging on-finger kinesthetic feedback for on-body computing.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in ubiquitous and mobile computing**; **Haptic devices**.

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KEYWORDS

Kinesthesia, notifications, finger-augmentation devices, experiment, user experience, kinesthetic feedback, index finger

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1 INTRODUCTION

Notifications, prevalent on mobile devices, drive distinctive consumption practices of users who feel informed, excited, and connected when receiving them, but also annoyed, interrupted, and anxious when notifications are either overwhelming or absent [48,57,70,83]. As personal computing paradigms evolve, notifications are increasingly available on more devices, such as wearables [32,39,69], and across devices [18,40,85], two aspects that intensify the plethora of user experiences constituting the “notification culture” [1].

On-body interaction [11], an emerging personal computing paradigm, where the user’s body is repurposed for I/O [28,29,43], is especially relevant in this context. In this paradigm, *notifications are represented by feedback delivered via the user’s body instead on a device outside the body*, which challenges the way designers conceptualize notifications and users experience them. On-body output affects user agency, instrumental for interacting in the real-world, which becomes shared with a computer in the new paradigm. For example, Figure 1a shows a volitional extension of the index finger, during which muscle and joint receptors pick up on their deformations and signal the corresponding information to the brain,

which forms *kinesthetic awareness* of the position and movement of the index finger from internal stimuli only [60]. Figures 1b and 1c depict the same effect, except that user agency is lost to the device extending the finger to deliver an embodied notification, e.g., a discreet extension (1b) to signal new email or a conspicuous one (1c) to alert about an error. Unlike mobile notifications that are *outside* the body, embodied notifications such as these feel *inside* and, thus, take advantage of a new sensory channel to address user attention at unprecedented engagement, with output levels ranging from subtle to alert. While user behavior with mobile notifications has been well-documented [26,41,48,56,57,70,83], new devices and output modalities such as these require dedicated attention from the scientific community to understand users' needs, attitudes, and behavior when notifications are presented in new ways.

Unfortunately, only a few systems have experimented with on-body notifications and, thus, the current understanding of how to design for this new output modality and how users perceive it is very limited. Moreover, prior work has primarily focused on the novelty of the underlying technology [22,43,64], and was limited by it to gross movements of the arm [64] and wrist [22,43], which has prevented exploration of more subtle notifications at finger level. In this context, the community is lacking a proper examination of user perception of notification delivery in the emerging on-body computing paradigm. To address this aspect, we focus on *on-finger kinesthetic notifications*, and make the following contributions:

- (1) We formalize “fingerhints” as on-finger kinesthetic output, delivered beyond user agency, with a technology-agnostic descriptive language and design space with three dimensions: flexion-extension, abduction-adduction, and dwell time.
- (2) We report results about the user experience of fingerhints from an experiment with N=21 participants: overall good level of usability (SUS=67.4, UMUX=62.5) given the conspicuous nature of our device, low perceived creepiness (25.1/100), and moderate to high acceptability for several locations (3.4/5) and audiences (4.0/5). To contextualize these results, we discuss them in relation to our participants' personality traits and attitudes toward notifications. We also present an analysis of 210 fingerhints elicited to implement ten common notification types, e.g., text messages, social media, etc., and report an overall low level of agreement (AR=.047) between users, but high perceived comfortability (5.4/7), memorability (5.5/7), and goodness of fit (5.4/7) within users.
- (3) In a follow-up experiment with N=11 new participants, we run a comparative evaluation of the wearable comfort and perceived creepiness of our fingerhints device against four commercial finger- and hand-augmentation devices. Our findings show that our device fares well with low perceived emotion (3.4/11), harm (2.1/11), change (3.7/11), and anxiety (1.6/11). We complement these results with insights on the perceived usability and social acceptability from the experience of one participant who wore our device for eight hours during various activities in their daily life.
- (4) Based on our empirical findings, we outline several implications and future work opportunities for integrating fingerhints, as on-finger kinesthetic feedback, into the on-body computing and interaction paradigm.

2 RELATED WORK

We discuss prior work leveraging kinesthetic and proprioceptive sensations for the design of interactive computer systems, and relate to studies that have documented user perception and behavior with notifications presented on mobile and wearable devices. We start with an overview of *kinesthesia* and *proprioception*.

2.1 Kinesthesia and Proprioception

When a body part moves and changes position, the tissues around the joints that leverage those movements are being deformed. The deformations are picked up by mechanically sensitive receptors from the skin, muscles, tendons, and ligaments that respond naturally to active movement [24], i.e., the kinesthetic receptors. Kinesthesia, originally denoting this kind of “muscular sense” [9], is used to refer to both the *sense of movement* and *sense of position* of the body and its parts [60]. Scientific evidence has been accumulating [59] that muscle spindles play the major role in kinesthesia with additional information provided by receptors from the skin. While some authors [78] have used kinesthesia and proprioception interchangeably, others [59,60] consider proprioception more general in terms of subsumed sensations, including the senses of force, effort, and balance. According to the latter view, proprioception generically specifies the phenomena of “the body itself acting as a stimulus to its own receptors” [67] for conscious sensations [59], and kinesthesia strictly concerns body position and movement. We adopt this terminology to clearly specify the scope of our work about user perception of changes in the position and movement of fingers for on-body feedback.

2.2 On-Body, Proprioceptive, and Kinesthetic Interaction

Knowledge has been gradually accumulating in the scientific community about the design and engineering of on-body interaction [11, 74] with notable systems including OmniTouch [28], Armura [29], Botential [47], and LightSpace [88]. While most of these systems have focused on the body as a touch-sensitive surface and implemented output with projections, e.g., tapping on a video-projected menu on the palm [28], other I/O modalities have been examined to a much lesser extent. Bergström and Hornbæk's [11] systematic literature review identified new haptic sensations, such as those induced with EMS, among the opportunities still to be explored for on-body interaction. One such opportunity is “proprioceptive interaction” [43], which enables users to interact with their devices by feeling the pose of a body part instead of perceiving stimuli from outside the body. For instance, Muscle-Plotter [44] enhances pen-on-paper interaction by having the user's wrist steer automatically to produce drawings mediated by the computer. Pose-IO [43] leverages EMS of the forearm muscles to output hand poses, e.g., the user's wrist tracks with the video playhead during a presentation. MuscleIO [22] is a system worn on the forearm that actuates the wrist via EMS to deliver notifications in the form of three progressively increasing dorsal extensions of the hand to which users can respond with “accept” or “refuse” wrist gestures. We connect to this prior work by adopting the same perspective of *body movement used for output by an interactive system to complement user agency*, but with a distinct focus on more subtle finger movements.

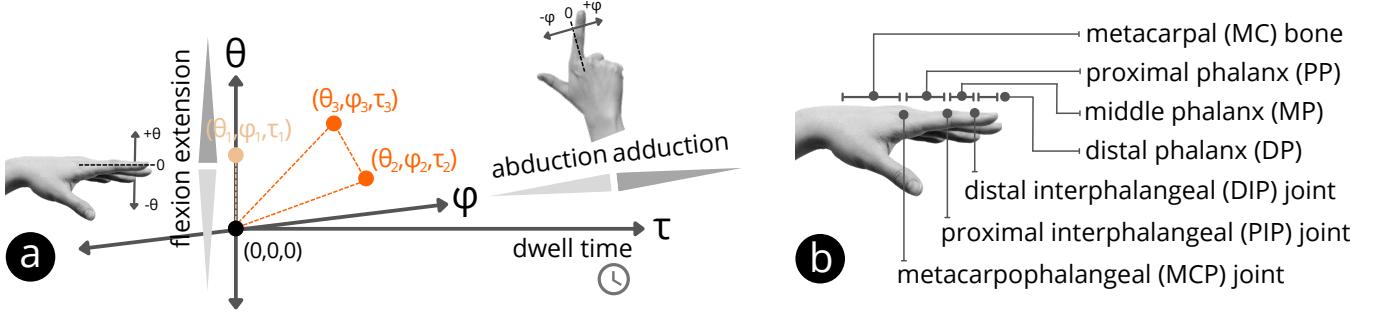


Figure 2: (a) A space with three dimensions, θ , ϕ , τ , for specifying on-finger kinesthetic feedback. (b) Anatomical terminology.

2.3 User Behavior and Attitudes Toward Notifications

There is a large scientific literature documenting user behavior with mobile [26,41,48,56,57,70,83] and wearable [12,33,40,63,69] notifications with the goal of designing more effective, less disruptive, user-centered notification delivery. A few examples follow.

Pielot et al. [56] collected subjective perceptions of real-world notifications during a one-week in-situ study with fifteen smartphone users and found that, while a larger number of notifications was associated with more negative emotions, social notifications made people feel more connected. A follow-up [57] on the effect of notification deprivation reported people feeling less distracted and more productive in the absence of notifications, but also anxious due to not being as responsive as expected in their social groups. Shirazi et al. [70] analyzed about 200 million notifications from more than 40,000 users and reported differences in their perceived importance, e.g., important notifications do not necessarily cause immediate attention, and important notifications are about people and events. Other works have proposed techniques to increase the effectiveness of notification delivery and reduce their disruptive effect. For example, Fortin et al. [26] found that vibrotactile and auditory notifications induce skin conductance responses, which can be picked up with wearable sensors to predict user perception of a notification following its presentation. Mehrotra et al. [48] reported effects of users' personality traits on the response time and perceived disruption of smartphone notifications, e.g., extrovert people are more inclined to feel disrupted by a notification, a result that can be exploited for personalized interruptibility models.

Notifications delivered with wearable devices have equally been examined. Shirazi et al. [69] reported that the perceived importance of a notification depends not only on the application but also the device type, e.g., smartphone or smartwatch, on which it is presented. Lee et al. [40] were interested in reducing redundant notifications between a smartphone and a smartwatch, and distinguished between "watch-preferable" and "phone-preferable" notifications, where the latter require users to take further actions. NotiRing [63] and PokeRing [33] are electronic rings designed to deliver notifications on the finger with specific modalities, e.g., light, sound, vibration, poke, and thermal for NotiRing and by stimulating locations around the proximal phalanx for PokeRing. Soma-Noti [12] is a family of under-clothing wearables that leverage on-skin sensations, e.g., poke, pinch, vibrate, heat, etc., as notification channels.

2.4 Summary

Our analysis of the scientific literature revealed extensive work on smartphone/smartwatch notifications and increasing work on kinesthetic I/O for the emerging on-body computing paradigm, but little examination of interactive computer systems at the conjunction of these two areas. Next, we introduce a formalization of fingerhints as on-finger kinesthetic output.

3 FORMALIZATION OF ON-FINGER KINESTHETIC NOTIFICATIONS

We introduce in this section "fingerhints," our mathematical formalization and design space for on-finger kinesthetic notifications. To this end, we consider three dimensions along which finger movements can be described (see Figure 2 for illustrations):

- (1) *Flexion* and *extension* are the primary movements of the fingers. *Flexion* is movement that decreases the angle between the two adjacent bones of a joint, e.g., between the phalanx and the metacarpal bone at the metacarpophalangeal (MCP) joint, as the finger moves toward the palm. *Extension* is the opposite of flexion, where the angle between the two adjacent bones increases as the finger moves away from the palm. We specify flexion and extension with changes in the angle measured between phalanges; see the vertical axis θ in Figure 2a and Figure 2b for the anatomical terminology. Finger extensions at angles $\theta > 0^\circ$ are also called *hyper-extensions*.
- (2) *Abduction* and *adduction* are finger movements performed at the MCP joint. *Abduction* occurs when the finger moves away from the midline of the hand (i.e., abduction spreads the fingers), while during *adduction* the finger moves toward the midline (i.e., adduction brings the fingers together). We measure abduction and adduction with the ϕ angle defined with respect to the axis of the phalanx aligned with the metacarpal (MC) bone; see Figure 2a.
- (3) Figure 2a also shows a time axis, along which τ specifies the *dwell time* while the finger is kept in the pose (θ, ϕ) at a given joint, e.g., a 500ms-long 10° extension and 5° abduction of the index finger at the MCP joint.

Angles θ and ϕ specify a diversity of poses at each finger joint and, along with τ , movements of different duration between those poses. By adopting these dimensions, we build on top of hand modeling approaches used to specify gestures for input in HCI [72,76,93] and

manipulation aspects of robot motion [51], which we apply from the new perspective of on-body interaction [11]. We refer readers to [5, 10, 31, 35] for the physical limits of finger movement, e.g., Jones and Lederman [35] reported maximum flexion of 85° at the MCP joint, extension of about 30° – 40° , and a combined abduction and adduction range of 30° for the index finger. Using the formalism of θ , ϕ , and τ , we define on-finger kinesthetic notifications as movements that put the finger into a series of n poses at joints j :

$$\gamma = \{(\theta_{i,j}, \phi_{i,j}, \tau_{i,j}) \mid i = 1..n, j \in \{MCP, PIP, DIP\}\} \quad (1)$$

For example, a simple fingerhint leverages an external force to put the index finger into the pose $(\theta_1, \phi_1) = (30^\circ, 0^\circ)$ at the MCP joint with a dwell time of $\tau_1 = 500\text{ms}$, after which the force stops and the finger is free to resume its previous state. The corresponding description is $\gamma_1 = \{(30^\circ, 0^\circ, 500\text{ms})\}$; see Figure 2a. A more complex fingerhint puts the index finger into the pose $(\theta_2, \phi_2) = (20^\circ, 10^\circ)$ at MCP for $\tau_2 = 500\text{ms}$ and to $(\theta_3, \phi_3) = (40^\circ, 5^\circ)$ for $\tau_3 = 750\text{ms}$. The corresponding fingerhint is $\gamma_2 = \{(20^\circ, 10^\circ, 500\text{ms}), (40^\circ, 5^\circ, 750\text{ms})\}$; see the polyline representation in Figure 2a. Next, we present an experiment designed to evaluate the user experience of fingerhints specified as sets of individual states (θ, ϕ, τ) .

4 EXPERIMENT #1: THE USER EXPERIENCE OF FINGERHINTS

We conducted a controlled experiment to measure the user perception of fingerhints delivered by a custom-made finger-augmentation device as well as to elicit preferences for suitable fingerhints corresponding to common notification types.

4.1 Participants

Twenty-one people (14 male and 7 female), aged between 20 and 37 years old ($M=23.9$, $SD=4.4$), participated in our experiment following recruitment via mailing lists and convenience sampling. All participants were smartphone users and some were also using wearables, e.g., 38% reported using smart earbuds frequently, and 33% owned smartwatches or fitness trackers; see Figure 3 for detailed demographics about our sample of participants.

4.2 Apparatus

We developed a finger-augmentation device that puts a finger into a controllable state of hyper-extension. The device can be used with any finger, and we placed it on the index finger in our experiment.¹ The largest part of the device is a 3D-printed platform affixed with velcro straps to the dorsal surface of the hand to ensure a steady fit for hands of different sizes; see Figures 1 and 4. A Hitec HS-422 servomechanism² (3.3kg/cm maximum torque and 0.21s/60° speed at 4.8V), connected with a nylon thread to a 3D-printed support for the distal phalanx, implemented fingerhints as series of (θ, ϕ, τ) poses at the MCP joint with $\phi=0$. We chose nylon due to its high Young's modulus with a breaking strength of 10kgf (98.07N). We

¹We chose the index finger because of its multiple functions and large dexterity compared to the other fingers of the human hand, such as its frequent use for pointing, active touch, and prehensile movements [35]. From this perspective, where the index finger is an everyday important interface of the human body with the real world, the perceptions measured in our experiment will likely represent a lower bound of the user experience with fingerhints.

²<https://hitecrd.com/products/servos/analog/sport-2/hs-422/product>

modified the servomechanism by adding a wire to the internal potentiometer for reading its position in order to control the θ angles with $\leq 1^\circ$ precision. The assembly was driven by an Arduino Nano (16MHz CPU, 32KB, 45mm×18mm). For safety reasons, θ angles did not exceed the minimum between 30° and each participant's maximum extension of their index finger; see Figure 3b. The device weights 71g, mostly due to the servomechanism (45.5g).

4.3 Procedure

Our experiment consisted of four steps with a total duration of approximately one hour, as follows.

4.3.1 Step #1. Participants filled out a questionnaire about their use of mobile and wearable devices, general attitudes towards notifications, and completed personality, creativity, and index-finger dexterity tests; see Figures 3a to 3g.

4.3.2 Step #2. We placed the device on the participant's dominant hand and performed a calibration procedure to (i) adjust the length of the nylon wire connecting the fingertip to the servomotor and (ii) enter the participant's maximum finger extension angle, measured in Step #1, in the software running on our device as a safety measure. The default pose of the index finger while wearing the device corresponds to $\theta=0^\circ$; see Figure 4a. We then ran a prerecorded, 3-minute long sequence of fingerhints to demonstrate various extension angles and dwell times. We calibrated the duration of this sequence based on prior work on kinesthetic feedback (five minutes for the red hand game played with Pose-IO [43]) and the constraint to keep the total duration of the experiment reasonable for participants (sixty minutes in total, as in Muscle-IO [22]). The sequence was replayed under different conditions: the hand resting on a table (Figure 4a), standing up with the hand alongside the body (4b), holding the smartphone (4c), holding a large object with both hands (4d), resting the head in the hand wearing the device (4e), and shaking hands with the experimenter (4f), representative of a variety of everyday interactions involving the hand [23, 42, 45, 53, 65, 84]. The order of these conditions was randomized per participant. After each condition, we administered a short questionnaire with a mixture of user experience measures.

4.3.3 Step #3. At the half of our experiment, once the participants had formed an understanding of the capabilities of our finger-augmentation device, we asked them to think about suitable fingerhints, described as extensions θ of the index finger and dwell times τ , for several notification types, e.g., text message, news, social media, etc. For comfort purposes, participants rested their hands on a table as shown in Figure 4a. We instructed participants to propose fingerhints they thought were intuitive, comfortable, and memorable, and evaluate those characteristics using Likert scales. This part of our experiment represents an end-user elicitation study [89, 91].

4.3.4 Step #4. The participants filled out a final questionnaire containing measures about the overall perceived usability, social acceptability, and wearable comfort of fingerhints.

4.4 Design

Our experiment was a within-subjects design with one main independent variable, NOTIFICATION-TYPE, nominal with ten conditions

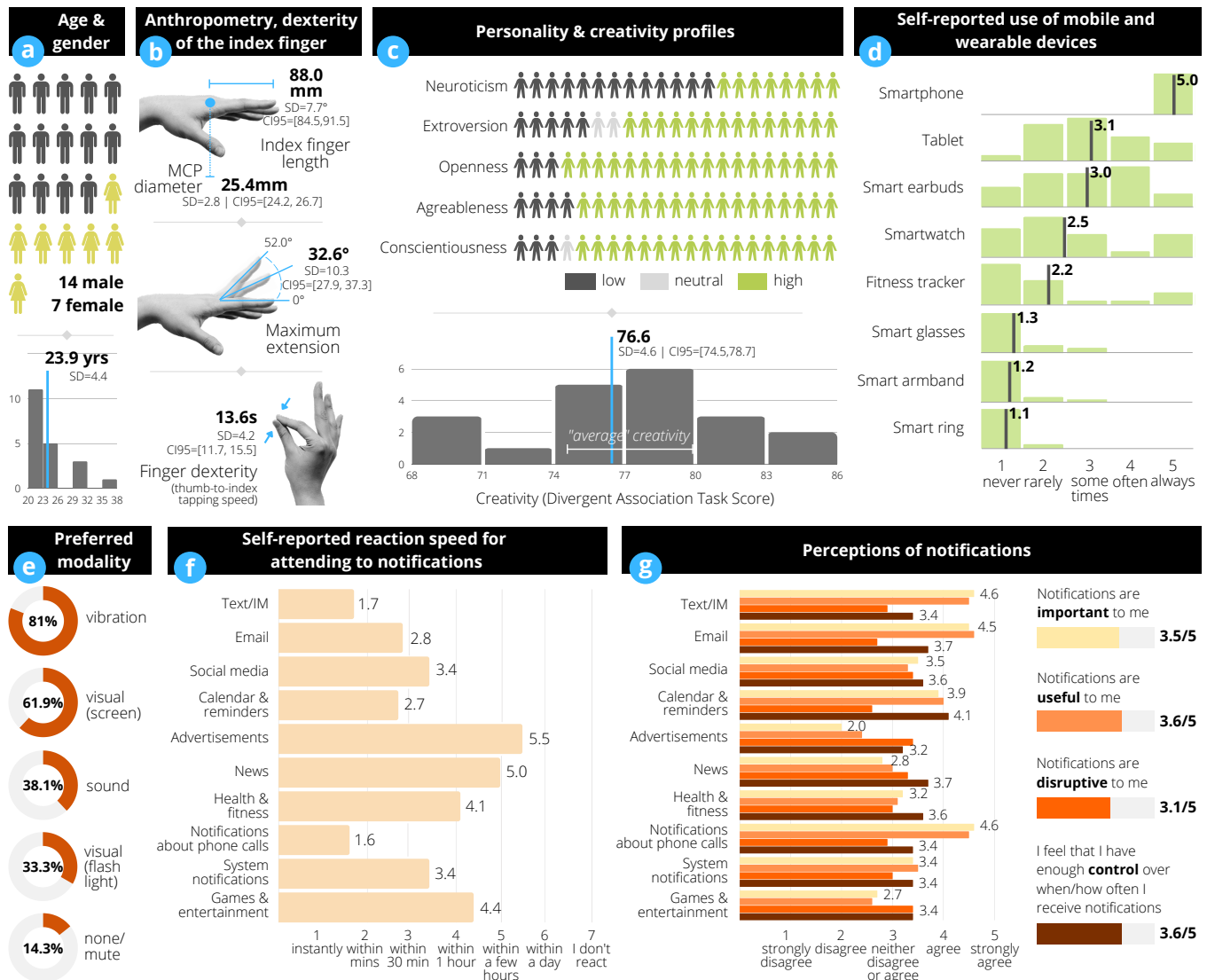


Figure 3: Demographic information about our participants collected to understand the user experience of fingerhints in context.

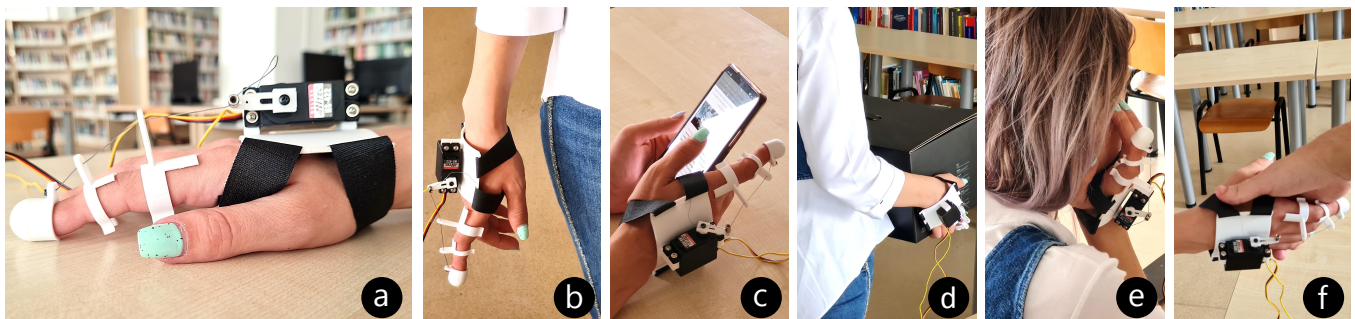


Figure 4: Activities involving the hand, during which fingerhints were delivered to the participants: the hand rests on a table (a), alongside the body (b), holds the smartphone (c) and a large object (d), supports another body part (e), hand shaking (f).

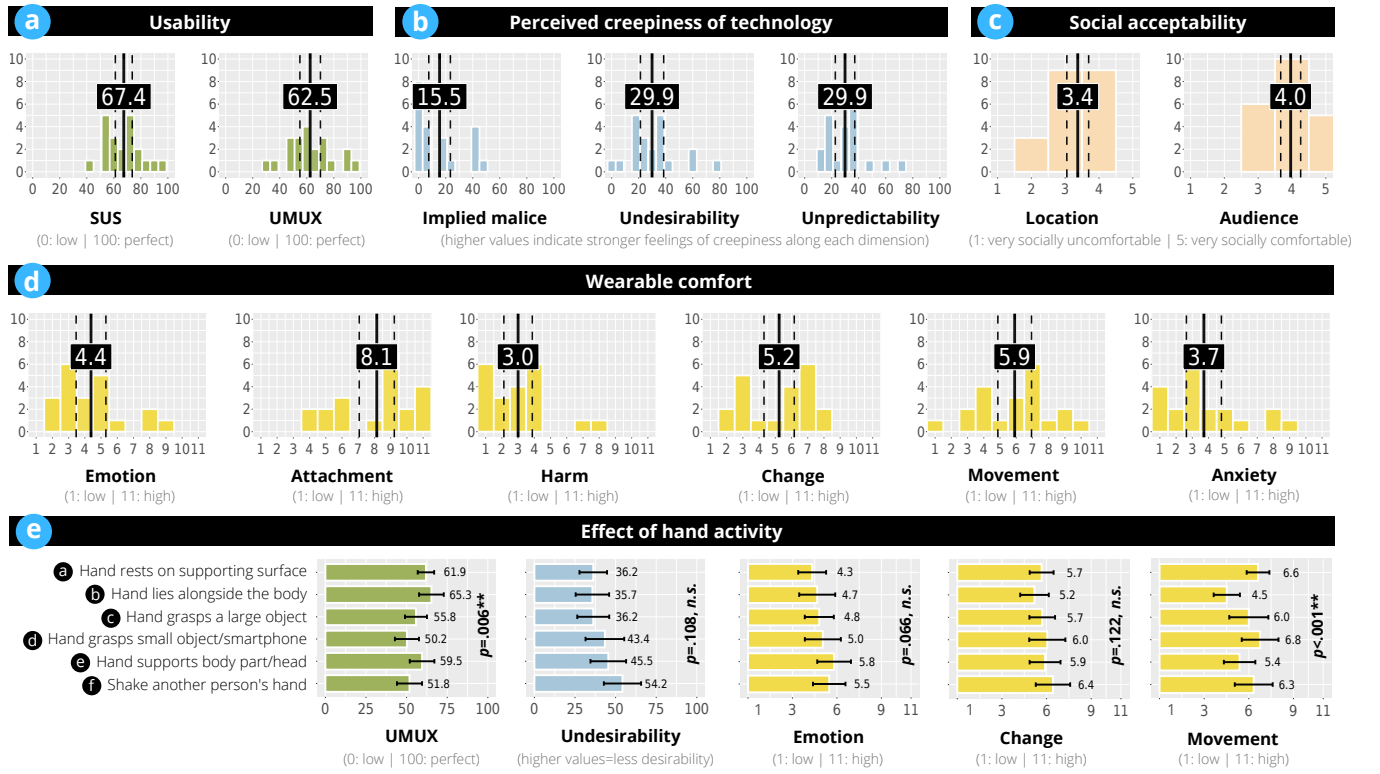


Figure 5: Perceptions of fingerhints: the overall experience (a-d) and the effect of the ACTIVITY involving the wearing hand (e).

(text/instant message, email, social media, calendar and reminders, advertisement, news, health and fitness, notification about phone calls, system notification, and games and entertainment), which we selected from previous work on mobile notifications [14,17,41,56,69,70,83,86]. By adopting the terminology of the end-user elicitation method [89,91], these conditions were the “referents” to elicit fingerhints in Step #3. Other independent variables were of local importance only: ACTIVITY in Step #2 (six conditions, see Figure 4), and AUDIENCE and LOCATION used in Step #4 to evaluate the social acceptability [61] of fingerhints, and are discussed in their respective subsections alongside the dependent variables.

4.5 Statistical Analysis

We used RM ANOVA to analyze the effect of NOTIFICATION-TYPE, ACTIVITY, AUDIENCE, and LOCATION in our within-subjects design, generalized eta squared³ for effect sizes, and Bonferroni corrections for multiple comparisons. We also used Pearson’s r (and Kendall’s τ for binary variables) to unveil interrelationships between dependent variables. Since r and τ are effect sizes, we interpret their statistical significance with bootstrapped ($n=2,000$) 95% CIs [20, p. 20].

4.6 Results: The Experience of Fingerhints

We start our analysis with the overall perception of the fingerhints experience, and we progressively focus on more specific aspects. In

³A measure preferred to partial eta squared for repeated measures designs [6], for which we used Bakeman’s [6, p. 383] recommendations for interpreting the magnitude of the effect, i.e., $\eta_G^2 = .02, .13$, and $.26$ for small, medium, and large effects, respectively.

our final questionnaire, we collected information about the overall experience of perceived usability [13,25], wearable comfort [37], social acceptability [61], and technology creepiness of fingerhints [92]; see Figure 5 for an overview of our results.

4.6.1 Perceived usability. We measured USABILITY with SUS⁴ [13] and UMUX⁵ [25]. The mean SUS score was 67.4 (SD=13.7), representing marginally acceptable usability close to “good,” according to Bangor et al.’s [8] acceptability ranges and adjective ratings for interpreting SUS scores; see Figure 5a. This result is encouraging given the novelty of fingerhints to our participants, the preliminary nature of our prototype, and the conspicuous intrusiveness of a device worn on a large portion of the hand. The usability level was independently confirmed by UMUX (M=62.5, SD=16.7).

4.6.2 Perceived creepiness. We evaluated fingerhints with the Perceived Creepiness of Technology Scale (PCTS) [92], a tool for measuring how creepy (e.g., intimidating, scary, unpleasant, uneasy) a new technology appears to users in an initial encounter. Following [92], we evaluated CREEPINNESS on three subscales—IMPLIED-MALICE, UNDESIRABILITY, and UNPREDICTABILITY—with 7-point Likert items from “strongly disagree” (1) to “strongly agree” (7), and

⁴SUS [13] consists of ten statements that elicit the degree of agreement using 5-point Likert scales with items from “strongly disagree” (1) to “strongly agree” (5). Answers are aggregated into a score between 0 (low usability) and 100 (perfect).

⁵UMUX [25] is the short variant of SUS [13], used in Step #2 to quickly evaluate participants’ perception of fingerhints under various activities. We re-administered UMUX in Step #4 to confirm, by direct comparison with SUS, the validity of our measurements from Step #2 on fewer dimensions of SUS.

normalized scores in [0,100]; see Figure 5b. Perceived CREEPINNESS varied between 9.3 and 50.9 ($M=25.1$, $SD=11.2$), revealing a large range of first impressions with a significant difference among the subscales (Greenhouse-Geisser $\epsilon=.889$, Mauchly's $W=0.876$ ($p>.05$), $F_{(2,40)}=5.442$, $p=.008$, medium effect $\eta_G^2=.138$). There was lower IMPLIED-MALICE ($M=15.5$, $SD=17.5$) compared to UNPREDICTABILITY ($M=29.9$, $SD=15.8$) and UNDESIRABILITY ($M=29.9$, $SD=19.0$), with a significant difference ($p=.008$) between IMPLIED-MALICE and UNPREDICTABILITY (Bonferroni corrections applied at $\alpha=.05/3=.0167$).

4.6.3 Social acceptability. Following [61], we evaluated SOCIAL-ACCEPTABILITY by considering AUDIENCE (nominal variable, six conditions: *alone*, *partner*, *friends*, *colleagues*, *strangers*, *family*) and LOCATION (nominal, six conditions: *home*, *sidewalk*, *driving*, *passenger on bus/train*, *restaurant*, *workplace*), which participants rated with 5-point Likert scales [3] from “very socially uncomfortable” (1) to “uncomfortable,” “neutral,” “comfortable” to “very socially comfortable” (5); see Figure 5c. We found positive ratings for both LOCATION ($M=3.4$, $SD=0.7$) and AUDIENCE ($M=4.0$, $SD=0.6$) and significant effects of LOCATION ($\epsilon=.725$, $W=0.326$ ($p>.05$), $F_{(5,100)}=12.386$, $p<.001$, large effect $\eta_G^2=.259$) and AUDIENCE ($\epsilon=.610$, $W=0.178$ ($p<.01$), $F_{(3,049,60,989)}=7.478$, $p<.001$, medium effect $\eta_G^2=.157$). Perceived social acceptability was significantly higher when *alone* ($M=4.5$) or with *family* ($M=4.2$) than with *strangers* ($M=3.2$), and also higher when at *home* ($M=4.3$) compared to *driving*, *bus*, *restaurant*, and *workplace* ($p<.001$, Bonferroni corrections at $\alpha=.05/(6\cdot5/2)=.0033$).

4.6.4 Wearable comfort. We evaluated WEARABLE-COMFORT using Knight et al.'s [37] Wearable Comfort Rating Scale with six dimensions: EMOTION (concerns about appearance and relaxation), ATTACHMENT (physical feel of the device on the body), HARM (physical effect, damage to the body), CHANGE (feeling physically different), MOVEMENT (the device physically affects movement), and ANXIETY (worry about the device, safety, and reliability). Following [75], we used 11-point Likert items from “low” (1) to “high” (11) to collect ratings on each subscale; see Figure 5d. We found a significant difference among subscales ($\epsilon=.677$, $W=0.301$ ($p>.05$), $F_{(5,100)}=21.963$, $p<.001$, large effect $\eta_p^2=.383$): higher ATTACHMENT ($M=8.1$, $SD=2.4$), CHANGE ($M=5.2$, $SD=2.0$), and MOVEMENT ($M=5.9$, $SD=2.3$) compared to EMOTION ($M=4.4$, $SD=2.0$), ANXIETY ($M=3.7$, $SD=2.4$), and HARM ($M=3.0$, $SD=1.9$) with significant differences ($p<.001$) between ATTACHMENT and all other subscales, and CHANGE and MOVEMENT with HARM and ANXIETY ($\alpha=.05/(6\cdot5/2)=.0033$).

4.6.5 The effect of hand activity. During Step #2, we asked participants to rate their perceptions of fingerhints when the hand wearing the device was involved in various activities, illustrated in Figure 4. To prevent administration of long questionnaires,⁶ we evaluated USABILITY with UMUX [25] and used only the EMOTION, CHANGE, and MOVEMENT subscales of WEARABLE-COMFORT [37] and UNDESIRABILITY of CREEPINNESS [92]; see Figure 5e. We did not find significant effects of ACTIVITY on EMOTION ($\epsilon=.701$, $W=0.203$ ($p<.05$), $F_{(3,506,70,118)}=1.640$, $p>.05$, *n.s.*) and CHANGE ($\epsilon=.718$, $W=0.365$ ($p>.05$), $F_{(5,100)}=1.249$, $p>.05$, *n.s.*). However, we found significant, small to medium effects on UNDESIRABILITY ($\epsilon=.701$, $W=0.307$

($p>.05$), $F_{(5,100)}=3.922$, $p=.003$, $\eta_G^2=.072$) and MOVEMENT ($\epsilon=.808$, $W=0.808$ ($p>.05$), $F_{(5,100)}=4.479$, $p<.001$, $\eta_G^2=.087$), since some of the ACTIVITY conditions required physical movement of the hand. Post-hoc *t*-tests detected significant differences between the hand alongside the body vs. the hand on the table and holding the smartphone for MOVEMENT, and between large object and shaking for UNDESIRABILITY (Bonferroni corrections applied at the level $\alpha=.05/(6\cdot5/2)=.0033$). More perceived MOVEMENT was equally reflected in different perceptions of USABILITY, revealed by a significant effect of ACTIVITY on UMUX ($\epsilon=.774$, $W=0.775$ ($p>.05$), $F_{(5,100)}=4.272$, $p<.001$, small to medium effect $\eta_G^2=.099$).

4.6.6 The effect of previous use of mobile and wearable devices. During Step #1, participants specified ownership and rated the frequency of use of various categories of mobile and wearable devices—*smartphone*, *tablet*, *smartwatch*, *fitness tracker*, *smart arm-band*, *smartglasses*, *smart earbuds*, and *smart ring*—using 5-point Likert scales with items from “never” to “rarely,” “sometimes,” “often” to “always”; see Figure 3d. We found no statistically significant correlations between the frequency of use of mobile/wearable devices and the experience of fingerhints, most likely because of the new form factor and technology of our fingerhints device, different from anything that our participants experienced before our study.

4.6.7 The effect of attitudes towards notifications. Following other studies [14,48,56,69,70], we also measured in Step #1:

- PREFERRED-MODALITY, in response to the question “How do you prefer receiving notifications on your devices?” with multiple selections possible: *visual (on screen)*, *visual (flash light)*, *sound*, *vibration*, and *none (mute)*.
- REACTION-SPEED, in response to “How long before you react to a notification?” with the following options: *instantly*, *within minutes*, *within 30 minutes*, *within 1 hour*, *within a few hours*, *within a day*, and *I don't react*.
- IMPORTANCE, as the level of agreement with the statement “Notifications are important to me,” using a 5-point Likert scale from “strongly disagree” (1) to “strongly agree” (5).
- USEFULNESS, “Notifications are useful to me,” measured with the same 5-point Likert scale.
- DISRUPTIVENESS, “Notifications are disruptive to me,” measured with the same 5-point Likert scale.
- CONTROL, “I feel that I have enough control over when/how often I receive notifications,” the same 5-point Likert scale.

These results are summarized in Figure 3: our participants considered notifications important, useful, yet somewhat disruptive, and were overall feeling in control over how often and when they were receiving notifications. We found that participants who felt more in CONTROL of when and how they received notifications provided higher USABILITY ratings ($r_{(N=21)}=.566$, $CI_{95\%}=[.251, .803]$ with SUS and $r_{(N=21)}=.472$, $CI_{95\%}=[.007, .770]$ with UMUX), and lower ratings of CREEPINNESS ($r_{(N=21)}=-.484$, $CI_{95\%}=[-.721, -.064]$). At the same time, participants who rated higher the perceived DISRUPTIVENESS of mobile notifications, also rated higher the IMPLIED-MALICE dimension of fingerhints CREEPINNESS ($r_{(N=21)}=.478$, $CI_{95\%}=[.150, .724]$). These findings suggest that appropriate mechanisms for managing fingerhints, similar to those employed on mobile and wearable devices by the participants who felt in control of

⁶Because we administered a questionnaire after each ACTIVITY, we aimed for a compromise between the parsimony of questionnaire items and the diversity of the information we could collect from our participants on the various dimensions of user experience.

their notifications, can render fingerhints usable, not disruptive. Also, the large majority (81%) of our participants reported their PREFERRED-MODALITY for receiving notifications on mobile devices via vibrations; see Figure 3e. We found a significant negative relationship between this preference and the UNPREDICTABILITY of fingerhints ($\tau_{(N=21)} = -.448$, $CI_{95\%} = [-.670, -.188]$), which suggests that transition to kinesthetic feedback could be facilitated by combining it with vibrotactile feedback.

4.6.8 The effect of personality traits. During Step #1, we administered Johnson's [34] personality test using an online tool.⁷ The test reports levels of NEUROTICISM (tendency to experience negative feelings), EXTROVERSION (engagement with the external world), OPENNESS (a cognitive style that distinguishes imaginative and creative from down-to-earth, conventional people), AGREEABLENESS (people that value getting along with others, cooperation, and social harmony), and CONSCIENTIOUSNESS (how impulses are controlled), which we normalized in [0..100]. Our decision to administer a personality test was inspired by Mehrotra et al.'s [48] findings on the relationship between users' personality traits and their smartphone notification-related behavior. Correlation analyses revealed that high USABILITY ratings were provided by participants with EXTROVERSION traits ($r_{(N=21)} = .497$, $CI_{95\%} = [.076, .763]$ with SUS), i.e., people that tend to be enthusiastic, action-oriented, like to talk, assert themselves, draw attention to themselves, and say "Yes" to opportunities. Although this finding could be attributed to extrovert people being overall open to newness, including new technology, we also found a significant positive correlation between CONSCIENTIOUSNESS and SUS ($r_{(N=21)} = .437$, $CI_{95\%} = [.015, .697]$), where conscientious individuals are known to be prudent, wise, cautious, and fond of purposeful planning. The participants with higher CONSCIENTIOUSNESS levels rated fingerhints lower on UNPREDICTABILITY ($r_{(N=21)} = -.459$, $CI_{95\%} = [-.761, -.033]$) and socially acceptable in front of various AUDIENCE types ($r_{(N=21)} = .480$, $CI_{95\%} = [.093, .751]$). These results indicate that the positive user experience of fingerhints (see Figure 5 for an overview) is not a mere effect of technology novelty. Moreover, the participants with AGREEABLENESS traits, i.e., people that are overall considerate, friendly, helpful, and concerned with cooperation and social harmony, provided high ratings for the SOCIAL-ACCEPTABILITY of fingerhints according to both AUDIENCE ($r_{(N=21)} = .637$, $CI_{95\%} = [.333, .844]$) and LOCATION ($r_{(N=21)} = .690$, $CI_{95\%} = [.491, .844]$), which strengthens our confidence in the high perceived acceptability of fingerhints.

4.7 Results: Preferences for Fingerhints

In Step #3, we elicited preferences for fingerhints in response to the conditions of the NOTIFICATION-TYPE independent variable. We video recorded the sessions and measured the extension angles θ using a goniometer, from which we computed:

- LENGTH of fingerhint γ as the number of poses n specifying the underlying finger movement from Eq. 1.
- DURATION of fingerhint γ as the sum of the dwell times of the constitutive finger poses, $\sum_{i=1}^n \tau_i$.

- EXTENT as the maximum of the extension angle of the fingerhint, $\max_{i=1..n} \{\theta_i\}$.

We also collected the following measures, specific to end-user elicitation studies, which we adapted from [27,52,91,94]:

- GOODNESS of the association with the notification type, measured on a 7-point Likert scale from "strongly disagree" (1) to "strongly agree" (7) in response to "The fingerhint I picked is a good match for its intended purpose."
- COMFORTABILITY, measured on a 7-point Likert scale in response to "The fingerhint I picked is comfortable."
- MEMORABILITY, measured on a 7-point Likert scale in response to "The fingerhint I picked is easy to remember."

Following recommendations to use the "computer model" of agreement analysis [82], we defined a dissimilarity function δ for fingerhints. We considered that fingerhints γ_p and γ_q proposed by the p -th and q -th participants were equivalent or substantially similar, a relation denoted with $\gamma_p \alpha \gamma_q$ [82], if they had the same number of constitutive poses, $n_p = n_q$, and the average differences in their θ angles and τ dwell times were smaller than thresholds ϵ_θ and ϵ_τ :

$$\gamma_p \alpha \gamma_q = \begin{cases} 1 & n_p = n_q = n \text{ and } \frac{1}{n} \sum_{i=1}^n |\theta_i^p - \theta_i^q| \leq \epsilon_\theta \\ & \text{and } \frac{1}{n} \sum_{i=1}^n |\tau_i^p - \tau_i^q| \leq \epsilon_\tau \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Based on this definition, we computed the agreement rate AR [82] for each NOTIFICATION-TYPE as:

$$AR = \frac{2}{N(N-1)} \sum_{p=1}^{N-1} \sum_{q=p+1}^N [\gamma_p \alpha \gamma_q = 1] \quad (3)$$

where N is the number of participants and $[\cdot]$ is Kronecker's delta that evaluates to 1 when the inner expression is true and 0 otherwise. Our choice for ϵ_θ was 10° , corresponding to an average difference in extension angles of about one fifth of the MAX-EXTENSION range observed in our measurements (Figure 3b). We approximated $\epsilon_\tau = 250\text{ms}$ according to the average reaction time for visuomotor human performance.⁸ AR takes real values in the [0, 1] interval.

4.7.1 Agreement analysis. Figure 6a shows very low AR values ($M = .047$, $SD = .047$), which indicate different user preferences for fingerhints. To verify that our results were not caused by employing too conservative criteria [79] when evaluating fingerhints similarity, we recomputed ARs with thresholds twice as large, $\epsilon_\theta = 20^\circ$ and $\epsilon_\tau = 500\text{ms}$, but still found little agreement ($M = .110$, $SD = .038$). A possible explanation is that people tend to propose highly individualized commands for new interactive technology with which they do not have any previous experience [49]; see Gheran et al. [27] for a similar observation from their end-user elicitation study about gestures performed with smart rings. The supplementary resources accompanying our paper present all of the 210 elicited fingerhints ($= 21 \text{ participants} \times 10 \text{ notification types}$) for future examination in the community. Next, we characterize the elicited fingerhints using several objective and subjective measures.

⁷Big Five Personality Test, <https://bigfive-test.com>.

⁸Reaction time statistics from over 81 million reaction time clicks, <https://humanbenchmark.com/tests/reactiontime/statistics>.

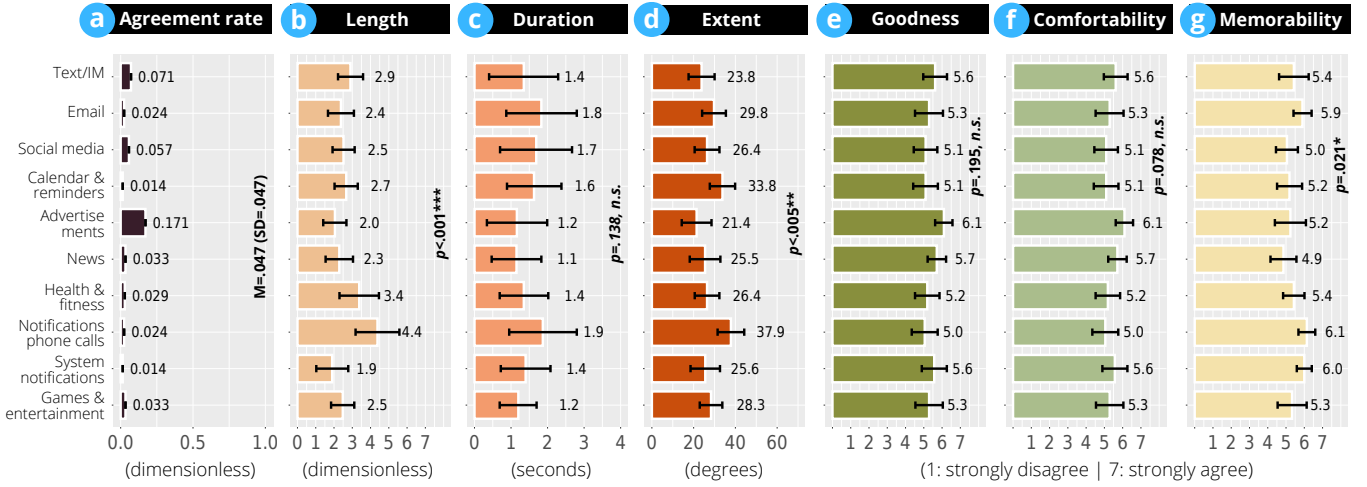


Figure 6: End-user elicitation results for fingerhints corresponding to common notification types.

4.7.2 Characteristics of the elicited fingerhints. We found a significant effect of NOTIFICATION-TYPE on the LENGTH ($\hat{\epsilon}=.584$, $W=0.032$ ($p>.05$), $F_{(9,180)}=3.479$, $p<.001$, $\eta_G^2=.137$) and EXTENT ($\hat{\epsilon}=.622$, $W=0.019$ ($p<.05$), $F_{(5,598,111.961)}=3.054$, $p<.01$, $\eta_G^2=.103$) of the elicited fingerhints, but not on their DURATION ($\hat{\epsilon}=.628$, $W=0.045$ ($p>.05$), $F_{(9,180)}=0.555$, $p>.05$, $n.s.$); see Figures 6b to 6d. Our participants proposed fingerhints of few poses ($M=2.69$, $SD=0.73$) with an average extension of 27.89° ($SD=4.85^\circ$), lasting about 1.47s ($SD=0.28$ s). While the significant differences in LENGTH and EXTENT can be attributed to differences in NOTIFICATION-TYPE, DURATION reveals a consensus among our participants, irrespective of NOTIFICATION-TYPE, that fingerhints should last at least 1s to be noticeable, but generally no more than 2s to prevent disruption.

4.7.3 Perceptions of the elicited fingerhints. Participants considered their fingerhints comfortable ($M=5.40$, $SD=0.34$), easy to remember ($M=5.46$, $SD=0.42$), and a good fit ($M=5.35$, $SD=0.32$) to the corresponding notifications; see Figures 6e to 6g. We did not find significant effects of NOTIFICATION-TYPE on GOODNESS ($\hat{\epsilon}=.608$, $W=0.048$ ($p>.05$), $F_{(9,180)}=1.635$, $p>.05$, $n.s.$) or COMFORTABILITY ($\hat{\epsilon}=.552$, $W=0.014$ ($p<.01$), $F_{(4,969,99.380)}=1.425$, $p>.05$, $n.s.$), but we detected a significant effect on MEMORABILITY ($\hat{\epsilon}=.563$, $W=0.008$ ($p<.001$), $F_{(5,069,101.389)}=2.435$, $p=.012$, small to medium effect size $\eta_p^2=.076$).

4.7.4 Effect of finger dexterity. We used a caliper and a goniometer to measure participants' FINGER-LENGTH (mm) between the MCP and the tip of the index finger, FINGER-DIAMETER (mm) at the MCP joint, and MAX-EXTENSION (degrees) as the maximum extension angle of the index finger. We also evaluated FINGER-DEXTERITY with a measure from NEPSY [38] as the time during which the index finger taps the thumb as fast as possible for thirty-two times in a row (lower values indicate higher dexterity); see Figure 3b. We found that the participants with higher FINGER-DEXTERITY rated higher the GOODNESS of their fingerhints ($r_{(N=21)}=.451$, $CI_{95\%}=[.025, .724]$), while participants that could extend their index finger more, leveraged this dexterity advantage to propose fingerhints with larger EXTENT ($r_{(N=21)}=.421$, $CI_{95\%}=[.020, .706]$); see Figures 6d and 6e. This result, corroborated

with the low agreement rates reported previously, has implications on personalizing fingerhints to match *both* users' preferences *and* dexterity abilities to feel comfortable on the finger.

4.7.5 Effect of creativity. Since one of the goals of the end-user elicitation model in HCI [82] is to inform design representative of user behavior, we wanted to learn whether our participants' creativity may have influenced the diversity of the elicited fingerhints. We administered Olson et al.'s [54] test of creativity,⁹ which reports scores in $[0..200]$.¹⁰ Our decision to administer a creativity test was inspired by the practice of previous elicitation studies [27,46] that analyzed participants' proposals in relation to their creativity levels. Our participants' CREATIVITY scores varied between 68 and 84 (Figure 3c), whereas average creativity falls between 75 and 80 [54]. We found a significant negative relationship between CREATIVITY and EXTENT ($r_{(N=21)}=-.405$, $CI_{95\%}=[-.705, -.024]$), i.e., more creative individuals preferred fingerhints with smaller extensions of the index finger, an interesting finding to examine in future work.

4.8 Summary

Our multi-faceted examination of the user experience of fingerhints revealed good perceived usability, low technology creepiness, and moderate to high social acceptability, all encouraging results given the preliminary nature and conspicuousness of our fingerhints delivery device. Contextualization of these findings with respect to our participants' personality traits and general attitudes towards notifications excluded a bias of technology novelty on their positive ratings of the fingerhints experience. Although agreement rates were too low to compile a consensus set of fingerhints for common notification types, the individual perceptions of comfortability, memorability, and goodness of fit were high, suggesting user-dependent customization of fingerhints. Next, we evaluate our device relative to other finger- and hand-augmentation devices.

⁹Divergent Association Task, <https://www.datcreativity.com/task>.

¹⁰According to Olson et al. [54], scores commonly range in practice from 65 to 90 and almost never exceed 100. Scores under 50 are *poor*, scores between 75 and 80 denote *average* performance, and scores above 95 are *very high*.

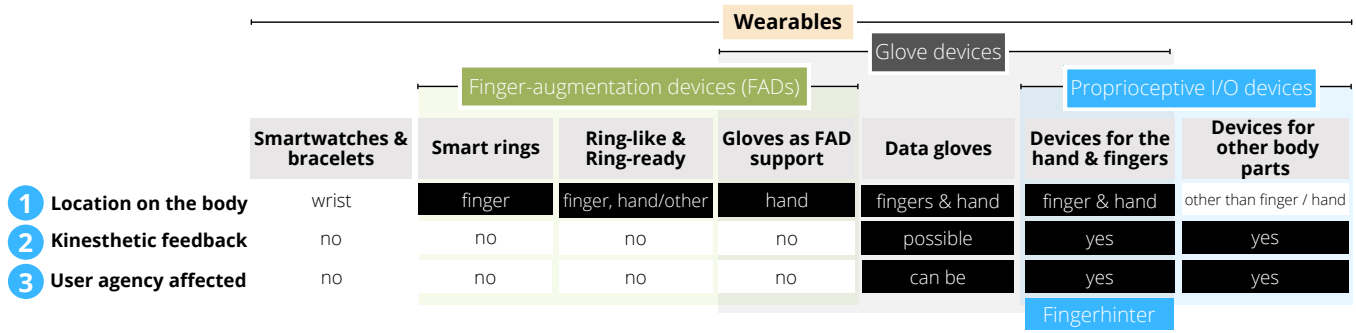


Figure 7: Fingerhinter compared to FADs [68,81], gloves [21], and proprioceptive I/O devices [43] in the large family of wearables [50,55] designed for the fingers and hand. Note how data gloves are the devices most similar to Fingerhinter.

5 EXPERIMENT #2: THE FINGERHINTS DEVICE IN THE CONTEXT OF FINGER AND HAND-AUGMENTATION DEVICES

We conducted a follow-up experiment to complement the findings about the user experience of fingerhints with perceptions of our device—referred in the following as Fingerhinter—in the context of other finger- and hand-augmentation devices. We start with a discussion of peer devices to which Fingerhinter is directly comparable in terms of form factor and features.

5.1 A Context for Our Fingerhints Device

Fingerhinter is a device that we prototyped to understand the user experience of on-finger kinesthetic feedback for on-body computing and interaction. While we adopted the application of notification delivery due to the prevalent use of notifications on mobile and wearable devices, Fingerhinter is not directly comparable to a smartphone or smartwatch, because of its contrasting form factor and output modality. Thus, to conduct an equitable comparison of Fingerhinter in context, it is key to identify its peers. To this end, we start from its main characteristics: (1) a wearable for the index finger and dorsal surface of the hand that (2) delivers kinesthetic feedback (3) meant to interfere with user agency in order to induce kinesthetic awareness. The first characteristic places Fingerhinter in the large family of wearables, so we used Motti and Caine’s [50] systematic literature review of human factors for wearables and Ometov et al.’s [55] survey of wearable technology to identify wearables designed for the fingers and hand: *smartwatches*, *bracelets/wristbands*, *rings*, and *gloves*.¹¹ Rings and gloves represent specific instances of finger-augmentation devices (FADs), which led us to Shilkrot et al.’s [68] survey, from where we also identified *gloves that support FADs*, and to Vatavu and Bilius’ [81] review of ring-based gestures, from where we identified *ring-like* (FADs that do not resemble a ring, but feature ring gestures) and *ring-ready* devices (FADs that can also be worn as rings). Finally, we considered *proprioceptive I/O devices* in the sense of Lopes et al. [43]. Figure 7 shows these classes of devices and how they position with respect

to the three characteristics of Fingerhinter. Following this analysis, Fingerhinter is at the intersection of FADs [68], gloves [21], and proprioceptive I/O devices [43], of which the closest form factors are data gloves since most of the proprioceptive I/O devices have used EMS on the forearm [22,43,44,64,77]. Having established devices directly comparable to Fingerhinter, we designed an experiment to collect perceptions of our device in the context of its peers.

5.2 Participants

We recruited eleven participants (8 male, 3 female), aged between 19 and 50 years old ($M=27.3$, $SD=10.8$), using the same procedure as in the first experiment. All of the participants were smartphone users, 46% reported using smartwatches or fitness trackers, and 46% smart earbuds. None of them participated in the first experiment.

5.3 Apparatus

We used the following four commercially available finger- and hand-augmentation devices: (1) 5DT Data Glove Ultra,¹² a lightweight glove for measuring finger flexion and abduction (Figure 8a); (2) Perception Neuron Lite,¹³ a motion capture finger-augmentation device with a hand strap form factor (Figure 8c); (3) Pinch Glove,¹⁴ an iconic VR data glove that senses index-to-thumb pinches (Figure 8d); and (4) Somatosensory Glove,¹⁵ a mechanical exoskeleton designed to sense finger and hand movements for control applications (Figure 8e). Although these devices form just a small sample of the available finger- and hand-augmentation devices, they provide a good comparison basis for Fingerhinter due to their different weights, sizes, form factors, materials, and hand coverage; see Figure 8, bottom for details about these characteristics.

5.4 Procedure

The participants wore each device during two activities: manipulation of a small object (smartphone) and large objects (boxes); see Figure 8. Devices were turned off since we wanted participants to focus on aspects of wearability only and not be distracted by functionality, which was different for each device. Each activity

¹¹Other form factors considered in [50], but not relevant for Fingerhinter, included: anklet, armband, belt, bra, contact lenses, chest mounted, earring, earpiece, glasses, headphone, head mounted, necklace, shirt, shoe. From [55], we focused on “wrist-worn and handheld wearables” category according to the placement of the wearable on the user’s body: smart rings, wrist bands, smartwatches, and gesture control devices.

¹²<https://5dt.com/5dt-data-glove-ultra>

¹³<https://cgicoffee.com/blog/2017/01/perception-neuron-lite-quick-test-review>

¹⁴<https://www.ultimate3dheaven.com/pinchglove.html>

¹⁵<https://www.amazon.com/LXSWY-Somatosensory-Wearable-Mechanical-Control/dp/B0BC15VRCL>

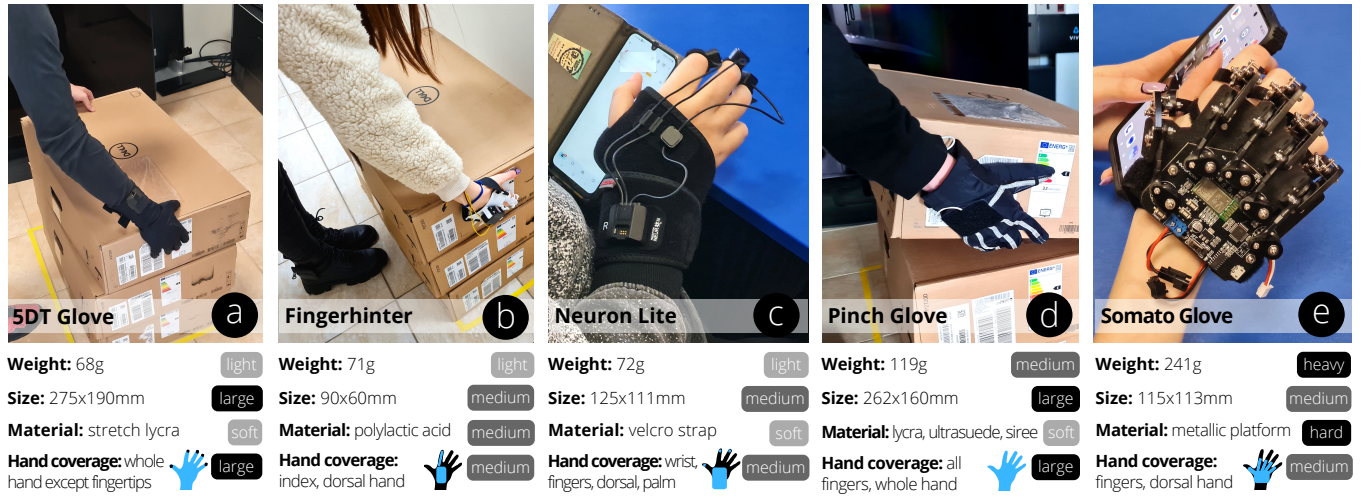


Figure 8: Finger and hand-augmentation devices from our experiment. Notes: all of the devices were worn during two activities: manipulation of a small object (smartphone) and large objects (boxes); devices are shown in increasing order of their weight.

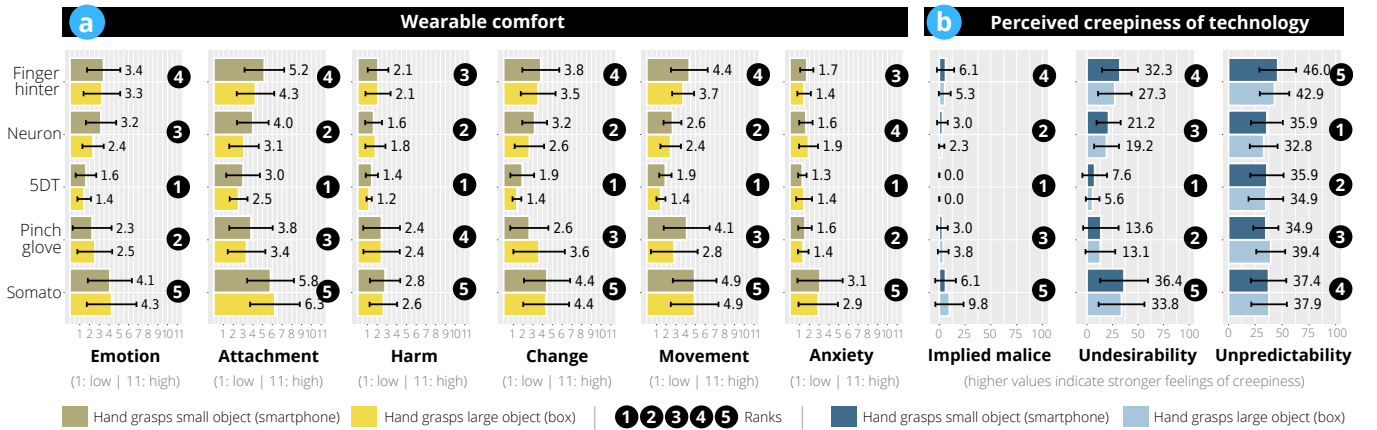


Figure 9: WEARABLE-COMFORT (a) and CREEPINESS (b) ratings for each combination of DEVICE × ACTIVITY.

lasted 3 minutes to keep the total duration of the experiment reasonable, of about one hour. For the small object condition, participants interacted with their smartphones. For the large object condition, the participants moved boxes between two marked locations inside a building. Overall, the participants wore the devices for 30 minutes = 5 (devices) × 2 (activities) × 3 (minutes) and, after each combination of DEVICE × ACTIVITY, filled out a questionnaire. The order of DEVICE and ACTIVITY was randomized per participant.

5.5 Experiment Design and Statistical Analysis

Our experiment was a within-subjects design with two independent variables: DEVICE (nominal, five conditions) and ACTIVITY (nominal, two conditions); see Figure 8. The dependent variables were WEARABLE-COMFORT [37] and CREEPINESS [92], also used in our first experiment. Since the devices expose different functionality, we were not interested in comparing their USABILITY. We employed the same statistical tests and procedures as in the first experiment.

5.6 Results

WEARABLE-COMFORT evaluations ranked Fingerhinter in the 3rd or 4th places—not the best, but not the worst either—in our sample of devices, where 5DT (the lightest device from our sample made of flexible lycra) scored best and Somato (the heaviest, hard materials) scored worst; see Figure 9a. We detected significant effects of DEVICE on EMOTION ($F(2.208,22.083)=4.113, p<.01, \eta_G^2=.114$), ATTACHMENT ($F(4.40)=5.968, p<.001, \eta_G^2=.147$), HARM ($F(2.205,22.051)=2.918, p<.05, \eta_G^2=.071$), CHANGE ($F(2.067,20.669)=5.154, p<.005, \eta_G^2=.109$), MOVEMENT ($F(2.309,23.088)=5.576, p<.001, \eta_G^2=.175$), and ANXIETY ($F(1.174,11.741)=2.991, p<.05, \eta_G^2=.116$), but no effect of ACTIVITY and no DEVICE × ACTIVITY interaction ($p>.05, n.s.$). Post-hoc t -tests (Bonferroni corrected at $\alpha=.05/4=.0125$ for contrasting Fingerhinter against its peer devices) showed significant differences with 5DT and Neuron for MOVEMENT, and with 5DT for CHANGE. These results are positive given that Fingerhinter is only a prototype, yet it fared well against commercial devices: low EMOTION ($M=3.4$), HARM

($M=2.1$), CHANGE ($M=3.7$), ANXIETY ($M=1.6$), and low to moderate ATTACHMENT ($M=4.7$) and MOVEMENT ($M=4.1$), respectively.

Perceived CREEPINENESS was low in terms of IMPLIED-MALICE ($M=5.7$ on the 0–100 scale), low to moderate for UNDESIRABILITY ($M=29.8$), and moderate for UNPREDICTABILITY ($M=44.4$); see Figure 9b. Although these results rank Fingerhinter in the 4th or 5th place in our sample of devices, we did not detect significant effects of DEVICE on IMPLIED-MALICE or UNPREDICTABILITY ($p>.05$, *n.s.*). We did find a significant effect on UNDESIRABILITY ($F(2.293,22.928)=6.890$, $p<.001$, $\eta_G^2=.171$), but post-hoc *t*-tests (Bonferroni corrected at $\alpha=.05/4=.0125$) revealed a significant difference only with respect to 5DT, the lightest device in our sample with the softest material. There was no effect of ACTIVITY and no interaction DEVICE $\times$ ACTIVITY ($p>.05$, *n.s.*). These results are very encouraging, showing that Fingerhinter does not elicit more creepy (intimidating, unpleasant, uneasy [92]) reactions than commercial devices designed for finger and hand augmentation.

5.7 Summary

Despite its preliminary nature, Fingerhinter fared well in terms of perceived wearable comfort and creepiness compared to a wide range of commercial devices. Next, we provide insights on the social acceptability and usability of Fingerhinter from the experience reported by a user who wore it for eight hours while engaging in his everyday activities.

6 PRELIMINARY INSIGHTS FROM USING FINGERHINTS IN THE WILD

To complement the findings of our in-lab experiments, we conducted a supplementary study “in the wild” [62] to gain insights following more prolonged use of fingerhinter than the one-hour exposure from our first two experiments. To this end, we recruited a new participant, James (25 years old, male, pseudonym used for anonymity purposes), which we asked to wear our Fingerhinter for eight hours continuously while carrying out his usual daily activities. Although studies with one participant only are very small scale, they are nevertheless informative and have been used in HCI, including for wearables [2,30,95]. While we use the insights gained from this study to complement and strengthen our findings about the user experience of fingerhinter, an extended in-the-wild study with more participants is recommended in future work.

6.1 Procedure

We introduced James to the concept of fingerhinter and demonstrated Fingerhinter. We then told him that he would receive fingerhinter periodically during the day and, after each, he had to send us a photograph of his whereabouts via WhatsApp. We implemented three types of fingerhinter: one finger pose ($\{(30^\circ, 250\text{ms})\}$, LENGTH=1, DURATION=250ms), two finger poses ($\{(10^\circ, 500\text{ms}), (30^\circ, 500\text{ms})\}$, LENGTH=2, DURATION=1000ms), and a complex fingerhinter of three poses ($\{(30^\circ, 500\text{ms}), (10^\circ, 750\text{ms}), (20^\circ, 1000\text{ms})\}$, LENGTH=3, DURATION=2250ms), respectively, informed by the findings of our elicitation experiment (Figures 6b–6d). Fingerhinter were presented in a random order and at random times during the day with an

average of four notifications per hour.¹⁶ There was no specific information for James associated to the notifications, which were just finger movements. We met again with James after 8 hours and asked him to evaluate the USABILITY and SOCIAL-ACCEPTABILITY of fingerhinter, two measures that we did not evaluate in our second experiment, and we debriefed him in an informal discussion.

6.2 Results

Fingerhinter were delivered in a variety of situations: mostly in the workplace (Figure 10a–d), but also while James was taking a coffee break (10e), walking on the sidewalk (10f), having lunch at a pizza restaurant (10g) in company (10h), arriving home (10i), and during his dentist appointment (10j). James reported inconveniences caused by wearing Fingerhinter while performing activities involving the hand and index finger, such as typing on the keyboard, writing with a pen, and unlocking his phone, which were expected given the preliminary, bulky form factor of our prototype. Regarding the latter, James suggested a form factor for the index finger only, not the hand. He also reported an unusual feeling of surprise when fingerhinter were delivered, “At some point I was walking on the street and felt like someone had grabbed my hand,” for which he suggested fingerhinter that would start slower not to feel sudden and prompt anticipation, “I got used to wearing it [the device], but the movements should be slower, when they are sudden it [the device] scares you.” However, he also considered fingerhinter “fun” and “useful” for messages that come from an important contact, are urgent, or require immediate action: “When I’m absorbed in my work, but need to leave not to be late for a meeting, the feeling of someone tugging on my finger would be really helpful.”

James’ evaluation of the USABILITY of fingerhinter revealed an SUS score of 50, lower than the average 67.4 found in our first experiment, but nevertheless in the range [42.5,95.0] representing our participants’ individual SUS evaluations; see Figure 5a. The UMUX score was 62.5, exactly the average observed in our first experiment. These results, following an in-the-wild experience, strengthen the confidence in our in-lab evaluations of the perceived usability of fingerhinter. Regarding the social acceptability of Fingerhinter, James reported having noticed reactions from curious people in public places, such as in the restaurant when “everyone was looking at the device,” and an inquiry from the dentist about the reason why he was wearing the device but, overall, James did not feel uncomfortable by these social interactions. His average ratings of SOCIAL-ACCEPTABILITY were 3.0 according to AUDIENCE (*alone, partner, friends, colleagues, strangers, and family*) and 2.8 according to LOCATION (*home, sidewalk, driving, bus, restaurant, workplace*), which are slightly lower than the scores obtained in our first experiment, yet they fall in the ranges [3.0,5.0] and [2.3,4.3] representing our participants’ individual evaluations for AUDIENCE and LOCATION; see Figure 5c. When we measured SOCIAL-ACCEPTABILITY only for the situations actually experienced by James during his day, we still found an average of 3.0 for AUDIENCE (*alone, partner, colleagues, strangers*), but an increase from 2.8 to 3.3 for LOCATION (*home, sidewalk, restaurant, workplace*).

¹⁶In total, 31 notifications were delivered during the 8-hour duration of the experiment, a value that we informed from the scientific literature reporting on the number of notifications received daily by users, e.g., 63.5 according to Pielot et al. [56].

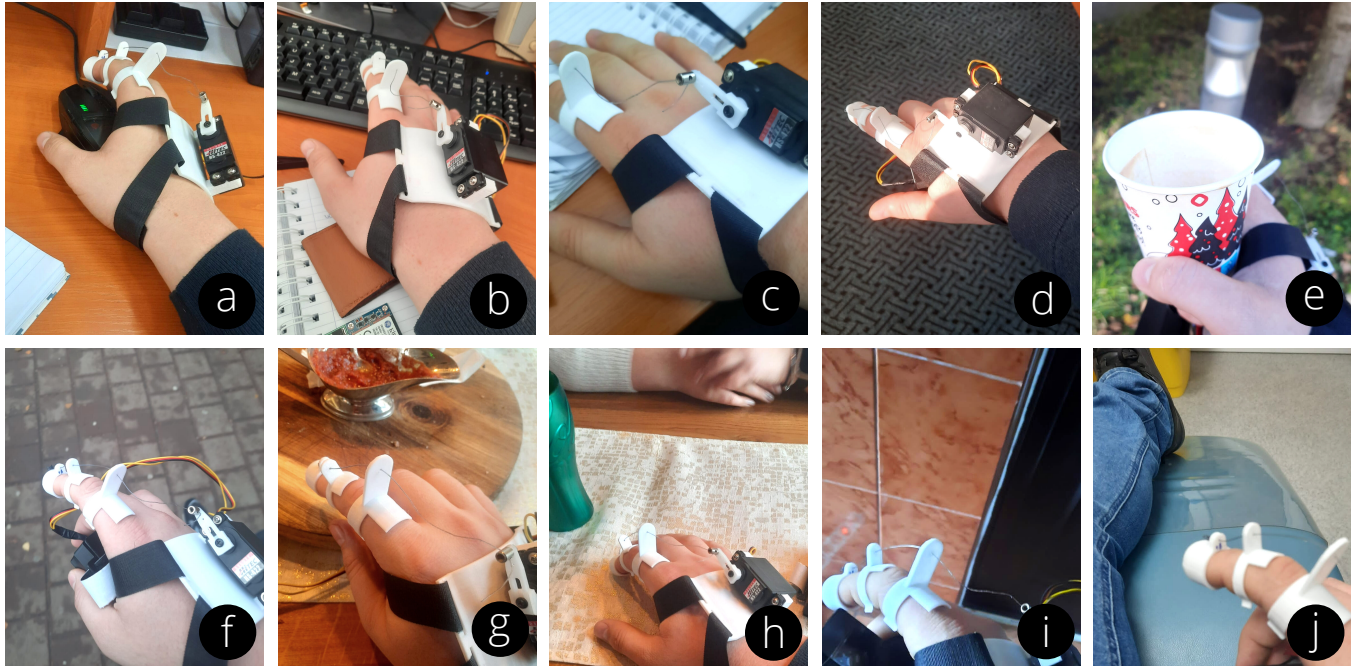


Figure 10: Photographs taken by James after receiving fingerhints (selected from a total of 31 fingerhints¹⁶ delivered during 8 hours): at the workplace (a-d), taking a break (e), walking (f), at the restaurant (g,h), at home (i), and at the dentist (j).

Overall, James' experience of prolonged use of fingerhints was mixed, primarily because Fingerhinter was not meant for deployment in real life. Further technical improvements, including miniaturization and other form factors, are envisaged in the future, but were not the scope of this work. Even so, the **USABILITY** and **SOCIAL-ACCEPTABILITY** results summarizing James' experience with fingerhints are similar to and, thus, strengthen the findings from our controlled in-lab experiments. Next, we capitalize on our findings to propose implications for on-finger kinesthetic feedback.

7 DISCUSSION

We present implications for fingerhints and suggest opportunities for future work in the context of the on-body computing and interaction paradigm. We also present limitations of our work and ways to address them in the future.

7.1 Recommendations for Researchers and Practitioners

Based on our findings, we outline practical implications for researchers and practitioners of on-body interaction.

7.1.1 Fingerhints design guided by quality properties. Our participants preferred fingerhints that were *fast* (between 1s and 2s), *simple* (composed of 1 to 3 finger poses), and with *easily perceptible* extensions (25° to 30°), large enough to induce the perception of change, yet *comfortable* to prevent harm and anxiety. The elicited fingerhints were also *highly personalized*. These empirical findings inform a set of practical quality properties—fast, simple, highly perceptible, comfortable, personalizable—to guide fingerhints design,

for which we provide corresponding quantitative ranges of the first four properties, as reported above, while personalization should be offered as an application feature; see next.

7.1.2 Fingerhints that match users' preferences, personality traits, and motor abilities. The analysis of the elicited fingerhints revealed low consensus, which suggests (i) designer-defined fingerhints that would form a standard or (ii) applications that enable users to personalize/define their own fingerhints similar to how vibration and auditory feedback can be personalized on smartphones.¹⁷ The quantitative ranges of the quality properties identified for fingerhints, e.g., one to three finger poses for *simple* fingerhints, can be used as guidelines to assist users during the definition and personalization of their own fingerhints. The correlations between personality traits and measures of the fingerhints experience second a recommendation from [48], proposed for smartphones, for building personality-dependent interruptibility models for groups of users sharing the same personality traits toward intelligent notification delivery. Moreover, since different users have different fine motor skills, personalization could also be addressed with ability-based [90] and ability-mediating [80] design. For example, the *availability* principle of ability-based design recommends using technology that is affordable and available, which suggests future work for integrating on-finger kinesthetic feedback in commercial wearables, such as electronic rings. The *mediation* principle of ability-mediating design fosters perception amplification to support new skills, e.g., processing on-finger notifications with little cognitive load at the periphery of attention [7] or even by-passing

¹⁷Change message notifications on iPhone, <https://support.apple.com/guide/iphone/change-notifications-iph62faab6a4/ios>.

conscious awareness altogether via automatic perception-action processes [19].

7.1.3 Integration of fingerhints in natural user behavior. Fingerhints are inextricably integrated with the hand, which may be involved in various activities, as examined in our experiments. Thus, a sixth quality property—*harmonious integration*—could be considered for fingerhints devices with the capability to understand context [85] and aspects of personal and social interruptibility [36]. An interesting implication concerns fingerhints delivery when users employ other devices, e.g., the smartphone. Since such a cross-device task received the lowest usability rating (UMUX=50.2) in our experiment, a practical implication is delivering fingerhints as complementary feedback when the smartphone is put away, e.g., in the user's pocket, by leveraging “phoneprioception” [87]. In this vein, we draw inspiration from Lee et al. [40], who distinguished between “watch-preferable” and “phone-preferable” notifications according to the action expected from the user, and we suggest “finger-preferable” notifications when the smartphone is not available or encumbrance affects smartwatch use [71]. Mixed delivery of fingerhints and smartphone/smartwatch notifications should be examined for facilitating gradual transition from mobile to on-body notifications in the context of the on-body computing paradigm.

7.1.4 Choice of technology for fingerhints. Body output can be implemented with different technology, of which EMS has been receiving increasing interest in HCI [22,43,44,64,77]. In this work, we preferred a technical solution involving a servomechanism, which was convenient to present participants with identical extensions of the finger at specific angles, e.g., $\theta=20^\circ$, in our controlled experiment, but also meant wearing a bulky device on the hand compared to EMS-based solutions. We expect that other technology and design choices, e.g., miniaturization of our prototype with a servomechanism of a smaller size, its potential integration into a ring-like device [81] or a smartwatch, or applying EMS to the forearm, are likely to have a positive impact on the perception of fingerhints and the fingerhints delivery device.

7.1.5 Perception of agency and body ownership. Kinesthetic signals, next to vision and touch, are important to create the perception of body ownership [60]. Fingerhints, however, challenge agency and affect this perception for the moving body part. Unlike mobile notifications that are *outside* the body, fingerhints feel *inside* and part of the user by hijacking the fingers for output. Nevertheless, unlike kinesthetic feedback involving larger body parts, for which reports revealed perceived loss of control, body hacking, and scariness [77], fingerhints can be discreet due to the locale and amplitude of the underlying movement. Two practical recommendations are designing fingerhints to feel calm and comforting following therapeutic rhythmic tapping [73] and integrating the quality characteristics of subtle interaction [58], e.g., fine movements, low embarrassment, low attentional and small space requirements. These recommendations are in line with our participants' preferences for fingerhints with extent angles of moderate magnitude (Figure 6d) that are perceived comfortable (Figure 6f). The need for calm fingerhints was equally felt during the prolonged use of the fingerhints device in our third study. An implication of these findings is that calm fingerhints (e.g., small to moderate extent, slowly starting, subtle, non-sudden

movements) are likely to be accepted by users and integrated with the perception of agency instead of creating a tension between the user and computer demanding control over the same body [77]. *Fingerhints as subtle interaction* could elegantly mitigate this tension to avoid technology acceptance barriers for on-body feedback [66]. In this context, we recommend examination of design options that complement, not challenge user agency.

7.2 Limitations and Future Work

There are several limitations to our experiment, for which we propose future work to address them. First, our Fingerhinter device was large, bulky, and worn on the index finger and, because of that, we believe that our results represent the lower bound of the user experience with fingerhints. Future iterations of lighter, less conspicuous devices, including for other fingers, could elicit higher usability, comfortability, and acceptability ratings. Second, we did not explore the abduction/adduction dimension in our experiments because a second servomechanism would have made the device even bulkier; instead, we preferred to reduce the scope of our analysis to perceptions of finger extensions only. Future work, involving a miniaturized servomechanism and form factor or a different technology, such as EMS, is recommended to this end. Also, future designs of fingerhints delivery devices that use servomechanisms should consider ways to reduce the noise produced by their mechanical parts. Although of small intensity (i.e., an average of 27.9dB for Fingerhinter,¹⁸ similar to that of a soft whisper [16]), noise reduction techniques would improve the delivery of subtle, discreet fingerhints in public places. Third, we measured the perception of fingerhints for the index finger only due to the distinctive qualities of this finger: its frequent use for pointing as an attention-directing gesture [4] and, during precision grips, the index finger is the first digit to make contact with the target and eye gaze is always directed toward its contact point [15]. However, examination of fingerhints delivered via other fingers may lead to interesting new findings, as would bimanual fingerhints, where devices are worn on both hands. We leave such interesting explorations for future work.

8 CONCLUSION

We reported the first examination of the user experience of on-finger kinesthetic feedback, for which we adopted the application area of notifications delivery. Our empirical findings revealed an overall positive user experience of fingerhints, which encourages their further examination for other practical applications in the on-body computing and interaction paradigm. To foster such future work, we make our dataset of 210 elicited fingerhints freely available at <http://www.eed.usv.ro/~vatavu>, together with R code that reads the data and computes the measures reported in this paper.

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¹⁸Measured from a distance of 1m from the servomechanism in motion using the Sound Meter app and a Samsung S20FE smartphone. The peak noise level was 32dB and the average 27.9dB in a quiet laboratory room with a background noise of 21dB.

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