One Ring to Rule Them All: An Empirical Understanding of Day-to-Day Smartring Usage Through In-Situ Diary Study

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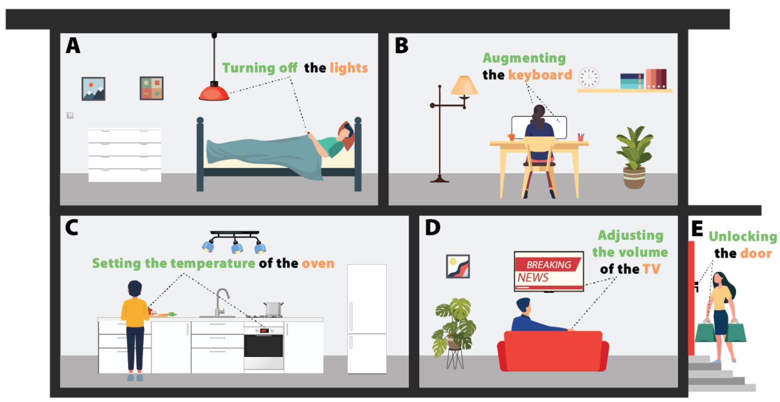

Fig. 1. Examples of how a smartring can augment our daily lives, and the range of tasks and devices within them. **(A)** Turning off the lights when the light switch is out of reach. **(B)** Augmenting the keyboard and/or multiple computing devices with shortcuts, commands, and functions performed on the ring. **(C)** While preparing food, using the ring to set the temperature of the oven. **(D)** Using the smartring to control the media on a TV. This can include volume, scrubbing, play/pause, and media selection. **(E)** Using the smartring as a biometric sensing device to unlock the front door when proximally close.

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Smartrings have potential to extend our ubiquitous control through their always available and finger-worn location, as well as their quick and subtle interactions. As such, smartrings have gained popularity in research and in commercial usage; however, they often concentrate on a singular or novel aspect of a smartring's potential. While with any emerging technology the focus on these individual components is important, there is a lack of broader empirical understanding regarding a user's intentions for smartring usage. Thus in this work, we investigate concrete and reported smartring usage scenarios throughout the daily lives of participants. During a two-week in-situ diary study (N = 14), utilizing a mock smartring, we provide an initial understanding of the potential tasks, daily activities, connected devices, and interactions for which augmentation with a smartring was desired. We further highlight patterns of imagined smartring use found by our participants. Finally, we provide and discuss guidelines, grounded through our found knowledge, to inform research and development towards the design of future smartrings.

CCS Concepts: • **Human-centered computing → Empirical studies in interaction design**.

Additional Key Words and Phrases: smartring; usage scenario; diary study; in-situ study

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1 INTRODUCTION

Over the years, personal computing has continually evolved with a focus on increased ubiquity, connectedness, and mobility. The emergence of smartrings, accompanied by their easy to access, always available, finger-worn location and novel one-handed interactions [5], build upon this personal computing paradigm and thus have begun to gain popularity as a wearable technology. Furthermore, the miniaturization of sensors have allowed both commercial products (e.g., *Oura Ring*[1] for collecting health data, *McLear RingPay*[2] for contactless payment, *Padrone Ring*[3] for controlling a pointer/mouse, or *FinchRing*[4] for XR interaction) and research prototypes (e.g., [1, 4, 5, 13, 65]) to demonstrate the potential of smartrings through the use of a variety of sensors and interactions. However, smartring technology, as listed in the examples above, is currently meant to serve or investigate an often singular purpose for an individual device or application.

We envision a future of personal computing where smartrings can help play a role in our connected and ubiquitous world. To achieve this, there is a need to ground our knowledge in how smartrings, as an emerging technology can be used, not only for a handful of interactive tasks, but throughout our daily lives. Furthermore, given the ecosystem of devices we utilize and interact with daily, understanding how an always available device, such as a smartring, can enhance personal computing is lacking. For instance, we explore what day-to-day activities and tasks allow for, or benefit from, smartring augmented control (e.g., work, media control, communication, etc.)?; What devices and other material objects do users want to control using a smartring (e.g., smartphone, smart TV, home appliances, etc.)? Furthermore, where and how do people perceive the greatest benefit of smartring connected control within their daily lives? Which interactions are considered appropriate for the control desired (e.g., touch, press, mid-air gestures, etc.)? What forms of feedback, if any, are thought to be beneficial (e.g., LEDs, screen, haptic, etc.)?

Thus, in this work, we set out to better understand people's intentions regarding potential smartring usage and how smartrings could be utilized. We conducted a two-week in-situ diary study in which 14 participants wore a mock smartring (i.e., a simple 3D-printed ring without any *smart* capabilities) throughout their daily lives. During the two weeks, we asked participants to fill out a questionnaire whenever they felt a smartring could augment

[1] https://ouraring.com, retrieved in July 2021
[2] https://mclear.com, retrieved in July 2021
[3] https://www.padrone.design, retrieved in July 2021
[4] https://www.finch-xr.com/ring, retrieved in July 2021

their ongoing activity and current task. Within the study, we also conducted a weekly semi-structured interview to further discuss their responses. Through an open coding analysis, we characterized and highlighted the tasks, primary activities, devices, and interactions that participants felt a smartring could provide ubiquitous and connected control for. Finally, leveraging prominent themes within the results, we provide design guidelines and current challenges as well as opportunities for future research in seamless connected and ubiquitous finger-worn personal computing.

The key contributions in this work are two-fold: **C1:** An empirical two-week in-situ diary study investigating the tasks, primary activities, devices, and interaction modalities people feel can be beneficially augmented through smartring usage; **C2:** A discussion and design guidelines encompassing the implications of our findings on future smartring design focused on perceived advantages of smartrings, the range of their potential use, connected control, and the mechanisms required to accomplish users' wants and needs. Taken together, our work provides context regarding the potential for future connected smartrings and aims to lead the research community towards a future generation of smartring technology focused on a broader goal of connected and ubiquitous personal computing.

2 RELATED WORK

In this section, we cover existing literature in (1) finger-worn computing, specifically smartring devices and we focus on (2) the benefits and considerations of in-situ studies.

2.1 Smartring Devices

Finger-worn computing has become increasingly studied in recent years and enjoys a vast landscape of research; which has notably been surveyed by Shilkrot et al. [49]. Smartrings offer several advantages with their always available and finger-worn location, their use while hands are encumbered, and the small and often unobtrusive form factor that can allow for subtle and ubiquitous one-handed interactions [2, 4, 5, 13]. Many novel approaches and studies have investigated smartring usage that aims to benefit from the above advantages.

2.1.1 Interaction Techniques. To mitigate the drawback of a reduced interaction space; researchers have: 1) embedded the ring with new miniaturized sensors (e.g., [1, 34, 58, 65, 66]), 2) designed novel interaction techniques using common sensors (e.g., [4, 5, 13, 14, 23, 53, 61]) and 3) elicited participants on users' preference for smartring interaction [12, 56]. Research has contributed many novel smartring input techniques, such as using physical buttons or pressure input [58], IMUs, which advantageously allow for a higher degrees of freedom from that of button input [15, 28], a trackpad [11, 26] which utilizes common touch interaction, magnetic tracking [1, 35], infrared sensors [34], thermal sensors [65], a joystick[5], and/or a camera [4]. While these all the above provide plausible input modalities, IMUs and trackpads provide an often natural and common input mechanism for users [12]. IMUs have even recently allowed for increasingly precise and expanded control than simple hand/finger flicks and motion gestures; to demonstrate this, Gupta et al. [15] proposed to measure the angle and rotation of the wrist through a smartring to perform text entry. The angular movements from the gyroscope and accelerometer are translated to act as a pointer on a keyboard. As the mechanisms for input become more fine-tuned, the applications for their use also increase. For instance, Kim et al. [26] proposed a trackpad on the smartring and used a customized keyboard layout to efficiently enter text.

2.1.2 Output Techniques. While most smartring literature focuses on the ring as an input device, some research has investigated output mechanisms [42, 62, 66]). For example, Zhu et al. [66] designed a thermal ring where participants were able to distinguish temperature change across four different areas of the circumference of the finger. To overcome the low just noticeable difference of thermal output, vibrotactile actuators have also been

[5]https://www.bynorth.com/

explored and allow for more rapid and patterned output through a relatively small form factor [18, 36]. Of the other modalities researched, lights and sound provide plausible feedback options [42], however may not always be suitable in public spaces or when the user is not paying close attention.

2.1.3 Smarting Usage Scenarios. Aside from the mechanics of smartrings, multiple contexts of use have also been explored. Prior work has investigated how to detect daily activities with a smartring such as walking, eating, cooking, teeth-brushing and writing [23]. Other singular use cases for smartrings include in-vehicle interactions that can be performed inside and outside the vehicle [13], music control while running [5]. These works showcase how a smartring can be used for secondary tasks rather than primary use, such as with a smartphone, smartwatch, and other devices. As there is limited functionality, due to a smartring's size, the contexts of use vary and capability as a connected device for control throughout our lives and must be explored. Additionally, external hardware such as augmented reality headsets, have utilized a smartring for connected interaction and control[6] This usage benefits from subtle interaction that is easily accessible, as compared to touch interaction on the headset itself or hand motion gesturing.

Through each of these works, smartrings show promise in their design, the ability to detect many gestures, either through touch or mid-air interaction, and the ability to interact in different contexts and situations. However, while these works focus on singular contextual use cases and interactions, there is a need to investigate concrete usage scenarios for a smartring throughout the daily lives of people. Understanding the user's need and mental model of and towards smartrings will undoubtedly help the research and development community in designing smartring devices for future wearable computing.

2.2 In-Situ Studies

In-situ studies provide an ecologically valid understanding of how a technology performs, or can be appropriated, within the contexts of our day-to-day lives. Such studies capture the context of use for technology and are particularly well-suited to gather in-the-moment insights into users' perceptions, wants, and needs [60], compared with in-lab studies (i.e., experiments, focus groups, brainstorming/design sessions) which often simply capture human behaviour [40] and can be affected by recall-bias [19, 63] thus not capturing the full extent of possible outcomes. When designing new and emerging technologies, in-situ studies have provided a host of valuable knowledge. More recently, with the apparition of smart-glasses, Häkkilä et al. [17] had participants wear a prototype pair of smart-glasses and probed them on their perceptions and how and when they wanted to use the smart-glasses. Also, before producing the personal digital assistant (PDA), a wooden prototype was created and was carried around by the entrepreneur Jeff Hawkins for one week [45]. We do note there are disadvantages to consider including the burden of manually reporting during an activity, frequent prompts, as well as compliance and retention when doing in-situ studies [22, 39, 44]. However, through the use of mobile devices, in-situ studies benefit from more frequent data capture [21, 54]. While few smartrings are available for consumer use, greater adoption and the full potential of this technology still requires an improved empirical understanding within our day-to-day lives; moreover, a concrete set of reported smartring usage scenarios has never been explored. Therefore, in a similar manner to the studies mentioned above, we aim to utilize in-situ study to better understand how a smartring can be used within our daily lives.

3 METHODOLOGY

In the following, we describe the design choices and reflect in detail how we probe our participants on their potential usage of a smartring.

[6]https://www.bynorth.com/

3.1 ESM vs. Diary Studies

To capture in-situ data, different methods have been used in the literature and particularly in HCI; such methods include the Experience Sampling Method (ESM)[7] (e.g., [8, 9, 54]) or diary studies (e.g., [6, 7, 10, 17, 24, 51]). ESM studies consist of alerts (ranging from 5 [29, 37] to 17 [55]) sent to the participant throughout a day, either randomly or non-randomly, notifying them to answer a questionnaire; the participant's response typically occurs in immediate succession of the alert. In our case, capturing a wide variety of tasks would require a high number of alerts. Ultimately, this could disturb the participants, increase their perceived burden, cause lower completion rates, and/or cause excessive or repeated responses [55, 64]. On the other hand, diary studies let the participants report an entry whenever the need arises. To ease the action of reporting within the diary study, researchers tend to directly prepare a questionnaire for the participants [10, 17, 51]. Furthermore, diary studies allow for participants to enter a response whenever desired, and reminders are provided throughout to prevent the well-known drawback that participants can forget their involvement [51]. For our study there was a need to gather a variety of tasks throughout the day, and as such, different and varied potential use cases for a smartring. Therefore we chose to use a diary study method as it allows more control for the participants and enables the capturing of potential usages that correspond directly to a their current activity and thoughts.

3.2 Diary Entry Questions

The diary questions were designed to collect both low- and high-level details, avoiding the challenge of receiving a range of granularity in responses across participants within a single question [29]. Throughout their day-to-day, when a participant felt that a smartring could be used, they could record a diary entry which asked the following questions (inspired by the questionnaire of Sohn et al. [51]):

- **Q1.** Where are you right now?
- **Q2.** What are you currently doing?
- **Q3.** Is there a specific task you are completing during your activity?
- **Q4.** What task do you feel the smartring could be used for within your current activity?
- **Q5.** Can you imagine what interactions you would like to perform on/with the smartring to accomplish this task?
- **Q6.** Are you currently wearing the smartring? If not, what is the main reason?
- **Q7.** How social is your environment right now?

Diary entries could be entered on either a smartphone or computer and on average took ~3 minutes to complete. One entry corresponds to one task that can be augmented by the smartring. Beyond explicit information about the smartring's potential to augment a task or device, we also inquired from our participants some in-situ information. This information provides further context allowing for a better understanding of where, when, why, and how participants may want to use a smartring. Importantly, questions within an entry could be left blank by participants if they were unsure or unable to produce a response. This was done so as not to induce a response that was not truly desired by the participant and to ease the effort needed for participation. Furthermore, we opted to not set a minimum number of responses over the two-week period for the same reason.

3.3 Mock Smartring

To better engage our participants in actively thinking about how a smartring could be incorporated within their daily life, inspired by earlier approaches [45], we created a mock smartring, i.e., a simple 3D-printed ring without any *smart* capabilities. We chose to provide a mock smartring over an actual smartring, as the latter would be impractical for the various sizes required for participants. Furthermore, having a mock smartring

[7] also referred to as the Ecological Momentary Assessment (EMA) method in some papers

Fig. 2. (Left) Design, specifications, and model of the ring used within the study. The mock smartring has a 2mm thick and 6mm wide loop. The diameters used for our mock smartrings were created between 16mm and 22mm and constructed in intervals of 0.5mm. The length of the top surface increases accordingly, from 13mm to 16mm, with larger diameters of the ring. (Right) An example of a participant wearing the mock smartring during their daily life.

abstracts away confounding, and at times bulky, hardware elements related to the physical device itself and instead allows participants to focus on the generation of responses. The mock smartring was worn by participants throughout the two-week in-situ diary study; see Figure 2. Wearing the ring was motivated by two main purposes: 1) to provide participants a physical sense of wearing a smartring, and 2) to keep participants aware of their involvement, as the study was performed remotely, throughout their daily lives.

We settled on providing a mock smartring that can be easily worn and provides a look slightly different to that of regular rings. Our mock smartring consisted of an open loop with a flat surface on top. A design with an open loop was chosen to provide a comfortable and non-restrictive fit, similar to the smartring designed by Zhang et al. [65], across a range of daily activities. Furthermore, the flat surface on top was included to provide participants with a potential input and/or output surface. To meet our specifications, we 3D printed our mock smartrings with resin which provides a smoother and more environmentally resistant material compared with printed filament.

3.4 Finger Choice

According to the reviewed literature, the majority of works on smartring computing designed their prototypes to be worn on the index finger [4, 11, 13, 15, 26]. Additionally, in a study on gesturing Vatavu and Bilius [56] found that participants most often chose to put the smartring on their index finger. Placing the smartring on the index finger allows for a broad range of input, as it enables thumb-to-smartring interactions and a high level of mid-air motion given the full movement range of the index finger [2, 27]. In line with these works, and so as to allow for broad interaction modality responses if desired, we asked our participants to wear the mock smartring on their choice of index finger. Of our participants, 8 chose to wear the mock smartring on their dominant hand's index finger and 6 on their non-dominant hand's index finger. Furthermore, we had participants size the mock smartring so that it would fit on the proximal phalanx. This part of the finger was chosen as thumb-to-smartring interactions can still take place while being a natural, and common, placement on the finger for a ring.

4 IN-SITU USER STUDY

4.1 Participants

To collect smartring use cases from a range of users, we recruited participants through our local university across an array of faculties and professions. There were no requirements regarding the number of devices participants interact with on a daily basis or their experience with smartring technology. Through poster and messaging platforms, we recruited 14 participants (5 females and 9 males). Participants' ages ranged between 20 and 38 (*M*

= 29; *SD* = 6.09), with 12 of the 14 participants being right-handed and 4 of the 14 participants typically wearing a ring daily on either their middle or ring finger. None of our participants owned a smartring. Our participants came from many different professional backgrounds including computer science, engineering, physics, law, and social services. To promote continued participation and in thanks for their time, we provided $40 as compensation to all participants, no matter their level of involvement so as to not promote forced responses.

4.2 Procedure and Task

At the beginning of the study, participants were informed of the study goal, compensation, asked to provide consent and consequently completed a short demographic questionnaire. Participation in our study then included three stages: (1) mock smartring selection and task description; (2) two-week in-situ participation and diary entry, as recommended by Stone et al. [52] and used by Sohn et al. [51] to study mobile information needs; and (3) two one-on-one online interviews.

(1) Participants were asked to try on a mock smartring that would fit and feel comfortable around their index finger at the proximal phalanx (the part of the finger closest to the knuckle). Participants received two rings of the same size in case of loss or breakage during the study period; participants were free to ask for additional mock smartrings if needed. We then briefed participants on the procedure of the in-situ diary entry study they would be partaking in over the next two weeks. Participants were then given access to the dedicated site for diary entry and explained how to record an entry (they did not have to carry a paper diary or dedicated device as in the work of Sohn et al. [51]). Note, that while we provided participants with our study goal and a broad definition of a smartring, we did not provide them with explicit examples of potential smartring usage, capabilities, nor examples of devices (smart and non-smart) the ring could connect with, so as not to bias their responses.

(2) Participants were asked to wear the ring as much as possible throughout their daily lives within the two-week study. Participants were to record an entry every time, and only when, they felt that their current task could be beneficially augmented through the use of a smartring; however, participants were instructed to only record an entry when it was safe for them to do so. Furthermore, to help our participants remember their involvement, and to remind them to think of smartring use cases, we sent them three daily notifications (at 9am, 1pm, and 5pm) on their smartphones.

(3) One of the authors conducted two online semi-structured interviews with each participant, a mid-study interview after seven days of participation, and a final interview at the end of the study, similar to other studies [10, 24, 29, 51]. Two interviews were conducted, so that participants could better recall the in-situ characteristics and responses they had provided, which were shown to them via screen sharing functionality during the interview. These were recorded (audio and video) and later transcribed (using dedicated software) to capture participants sharing, if desired, their conceived interactions, connected devices, and environments. The aim of the interviews were to gather feedback in three main areas: i) the general and overall progress of the study; ii) individual responses provided; which allowed the participant to elaborate on any details that may not have been captured within their diary entries; iii) clarification of responses recorded by the participant which were not clear to the researchers. Each interview lasted ~30 minutes.

5 ANALYSIS AND RESULTS

5.1 Number of Entries

A total of 223 diary entries were generated. We first examined all entries and discarded 26 of them due to incompleteness; as a result 197 valid entries remained for analysis. An entry was considered as incomplete when both Q4: *What task do you feel the smartring could be used for within your current activity* and Q5: *Can you imagine what interactions you would like to perform on/with the smartring to accomplish this task?* were unanswered; these two questions provide the crux of the information regarding the use of a smartring. Of the 197 entries, there

Table 1. Number of entries per participant throughout the two-week study period.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
1st Week	10	7	10	16	13	6	5	6	9	13	2	2	6	8
2nd Week	4	5	9	4	3	6	4	6	5	18	4	4	11	1
Total	14	12	19	20	16	12	9	12	14	31	6	6	17	9

was an average of 14 entries per participant (*SD* = 6.3) with a minimum of 6 and a maximum of 31 entries across participants. Table 1 summarizes the number of entries made by each participant during the study, separated by first and second weeks. Over the two-week period, 10 participants recorded less entries in the second week, 2 of them recorded the same numbers of entries and interestingly 4 participants recorded more entries.

5.2 Open Coding Procedure

We qualitatively analyzed all the entries through an open coding process. To specify, two of the authors separately coded a random subset of the entries to identify high-level themes, addressed in the next section, as well as a set of codes to characterize these themes. Then, the two authors came together to compare their findings, working to reach a consensus and thus created a coding schema. The remainder of the data was then individually coded using this schema and again, the resulting labeling of code to entries was then collectively discussed until full consensus was reached. In the end, all 197 entries were labeled with the mutually agreed-upon codes.

5.3 Categorization of Data

To better understand the potential connections and tasks that participants would want augmented through smartring usage, we coded the 197 entries across four key themes: ***activities***, ***tasks***, ***devices***, and ***interaction techniques***. Table 2 highlights each of these themes and codes, as well as provides counts of responses and examples within each coded theme. To reiterate, as we did not require responses to all questions from participants, some themes produce less than 197 responses and are detailed in their corresponding sections below.

Apart from analysing the individual results, a better understanding of future smartring connected and ubiquitous control lies in also exploring the relationship between themes. Furthering the broad range of tasks, activities, devices, and interactions proposed, the combinations of these coded themes within a single response also varied. Figure 3 highlights connections between each of the different themes. This figure can be used by researchers and designers who want to better understand the interconnected relationships between our themes and codes.

5.3.1 Activities. We defined activities by the ongoing activity being performed by the participant (e.g., *"running on the treadmill (Physical Activity)"* or *"cutting up vegetables for making dinner (Self-Care)"*). This theme provided in-situ context for the proposed smartring connection. Of the 197 total responses, activities were coded in all responses across 6 codes (Work/Study, Entertainment/Leisure, Day-to-Day, Self-Care, Physical Activity, Transportation). As these are not always mutually exclusive, if a combination of activity codes were feasible we first chose the code for which the smartring task augmentation was taking place, if this was not clear we then chose for the activity which was temporally longer.

Of the 6 codes, participants reported entries in a minimum of 3 codes and a maximum of all 6 (*M* = 4.5; *SD* = 0.8). This result shows that potential smartring usage was perceived across a range of daily activities. These include being stationary or mobile, hands-free or with hands encumbered, and during activities which require both high or low cognitive effort. Overall, the smartring was seen as a device that could help across many facets of daily life.

Table 2. Summary of the themes and codes used during the analysis of the study data with the number of occurrences per participant. The example column provides a high level idea of the types of responses found within an individual code.

Theme	Codes	Examples	Total	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Activities	Work/Study	Programming; Writing; School work; Manual work	60 (30%)	3	6	8	7	6	3	3	3	5	9	1	2	2	2
	Entertainment & Leisure	Watching/Listening to media; Reading; Playing games; Browsing social media	44 (22%)	4	4	2	2	1	3		3	4	10	4	1	4	2
	Day-to-Day	Completing errands; Walking a dog; Doing chores	33 (17%)	3	1		2	5	5	2	4	2	2			4	3
	Self-Care	Cooking; Eating; Brusthing teeth; Falling asleep	26 (13%)	3		3	4		1	3	1	3	4		2		2
	Physical Activity	Running; Working out in a gym; Cycling; Walking; Skateboarding	17 (9%)	1	1		3	1		1	1		4	1	1	3	
	Transportation	Driving; Taking public transport	17 (9%)			6	2	3					2			4	
Tasks	Media Control	Volume up/down; Play/Pause; Previous/Next; Scrubbing timeline	42 (22%)	1	8	1	2	2	2	2	3		10	3	2	3	3
	Range Control	Control thermostat; Control brightness; Scrolling content	34 (18%)	1	2	1	6	3	1		1	4	9		2	2	2
	Singular	Mute notifications; Turn on/off; Stop timer/ alarm	30 (16%)	2	1	3	3	1	3	4	3	2	5	2	1		
	Feedback	Display data (weather, notifications, etc.); Provide reminder; Locate smartphone	24 (13%)	5		1	3	2	1			4	2		1	4	1
	Transaction	Open/unlock doors; Pay fees; Log in/out	20 (11%)	2			2	3	2	2	3	1	1			2	2
	Communication	Sound/voice recorder; Call; Send messages; Share contact information	18 (9%)	2			2	4	3		1	1				4	1
	Keyboard/Mouse	Typing; Augment shortcuts; Switch tabs; Function keys	18 (9%)	1	1	6	2			1	1	2	2	1		1	
	Activity	Context awarness functionality; Physical activity tracking; Biometric tracking	4 (2%)			1							2			1	
Devices	Mobile Devices	Smartphone; Smartwatch; Tablet	50 (26%)	5	6	3	2	4	3	2	1	1	12	1		6	4
	Computer	Laptop; Desktop computer	43 (22%)	1	5	8	6	2	1	1	2	4	8	3	1		1
	Home	Stove/Oven; Thermostat; Shower; Lights; Blinds; TV; Front door	31 (16%)	2	1	1	4	2	1	4	5	3	2		3	1	2
	Standalone	Smartring without connection to another device	28 (15%)	5		2	5	3	1			4	3			5	
	Vehicle	Car infotainment unit; Car locks	14 (7%)					2	1	1	1		2		1	4	2
	Headphones/ Speakers	Bluethooth headphones; Speakers; Voice assistants	13 (7%)	1					4	1	1		3	2	1		
	Other	Augmented reality; Virtual reality; Gym	10 (5%)			1	2	1	1		2	2	1				
	Payment	Credit/Debit card machines; Pass readers	3 (2%)				1	1								1	
Interaction Techniques	Touch/Press	Tap; Double tap; Touch gestures; Press physical buttons	95 (59%)	10	1	6		5	5	7	8	10	14	6	4	8	7
	Multimodal	Touch/Press + Mid-Air Gesture; Touch/Press + Pressure; Touch/Press + Voice	24 (15%)	2	1	2	4	4	6	1	1	2	1			3	
	Mid-Air Gestures	Finger gestures; Hand gestures	18 (11%)		9	1	1			1						1	1
	Proximity	Tap/hold in proximity	14 (9%)	2		1	5				2					2	1
	Rotation	Spin around finger	4 (2.5%)			1	2	4									
	Voice	Natural language	4 (2.5%)				3		1						2	1	
	Other Interactions	Gaze; Pressure/squeezing	2 (1%)			1					1						

5.3.2 *Tasks.* Through analyzing the tasks people wanted to use the mock smartring for, we identified 8 codes: (Media Control, Range Control, Singular Control, Feedback, Transaction, Communication, Keyboard/Mouse Control, Activity Recognition). These tasks were the underlying augmentation that participants wanted to be able to perform with the smartring (e.g., *"use the ring to control the brightness (Range Control) of the lights in my room"* or *"hold the ring to my front door to unlock it (Transaction)"*). This theme provides the main form of understanding regarding the task that participants wanted to be able to complete with the smartring as well as the perceived level of control a smartring can provide.

Of the 197 total responses, tasks were coded in 190 responses across the 8 codes. Participants individually desired a broad range of tasks with a minimum of 3 and a maximum of 7 reported (M = 5.6; SD = 1.3). According to our classification, the most probed task was media control which represented 22% of our entries. Interestingly, Feedback is the fourth most probed task with 24 entries (13%) across 5 of the 6 activity codes, reflecting the fact that a smarting was seen as not only an input device but also an output device. Finally, we note that Communication was a task with 9% of total responses when either connected with Mobile Devices or while Standalone.

5.3.3 Devices. The devices theme allowed us to code specific devices that participants wanted to perform the potential smartring controlled task on. Responses included a mix of both smart and non-smart devices (e.g., *"Control the YouTube video on my phone (Mobile Devices) with the ring to scrub and change the volume"* or *"Change the temperature of the oven (Home) from the ring"*).

Of the 197 total responses, devices were coded in 192 responses across 8 codes (Mobile Devices, Computer, Home, Standalone, Vehicle, Headphones/Speakers, Other Devices, Payment Terminals). Again, we see a range of devices that participants individually wanted to perform augmented tasks on, with a minimum of 3 and a maximum of 8 devices to augment (M = 5.1; SD = 1.3). An almost majority of responses (48%) entailed Mobile Devices (26%) and Computers (22%) which are seen as typically smart and/or connected. Following this, the entire home was seen as an area where connections with the smartring were valuable at 16% of responses. The smartring itself was also seen as a standalone device (i.e., could be used without any others devices) with 15% of the responses suggesting the smartring could allow for functionality (i.e., feedback and/or activity recognition) without the necessity to pair to another device.

5.3.4 Interaction Techniques. Of the 197 total responses, interactions were coded in 161 responses across 7 codes (Touch/Press, Multimodal, Mid-Air Gestures, Proximity, Rotation, Voice, Other Interactions). Interactions that participants provided give insight into the desired form of input they envision a smartring allowing (e.g., *"I would swipe on the top of the ring (Touch/Press) to change the house temperature"*).

Per participant, we see a minimum of 1 desired form of interaction with a maximum of 6 (M = 3.2; SD = 1.3). In this theme, the Touch/Press code was overwhelmingly, 59% of the responses, the interaction modality of choice. Also suggested, was the ability to interact through Mid-Air Gestures, at 11% of responses, of which 73% were reported for Media Control. Participants reflected the need to further expand the input expressivity on the smartring through multimodal interactions techniques, most commonly Touch/Press + Mid-Air Gestures, which represented another 15% of responses. Finally, Proximity, reported for 9% of responses, involved holding or tapping the ring to objects; this was suggested for transactional tasks, such as paying or unlocking doors, as well as communicative tasks, such as quickly sharing contact information.

5.4 Patterns of Imagined Smartring Usage

Through participants' diary entries and the debriefing interviews, we uncovered patterns of imagined smartring usage to facilitate task augmentation; specifically, three main patterns arose: 1) the smartring for use to control non-primary devices and/or tasks while multitasking; 2) smartring use for encumbered and/or dirty hands; and 3) smartring use to control devices which are unreachable.

5.4.1 Multitasking Primary and Non-Primary Tasks. The mock smartring was often envisioned as a tool which could help control devices and/or accomplish tasks which were not the primary focus. This was exemplified when participants were multitasking, such as P1 who was *"listening to music and wanted to skip songs while working on the computer"* or P7 who was *"cooking and wanted to pause the TV in the background or like move to the next episode"*. Furthermore, the smartring was seen as useful to participants for control when unexpected needs arose such as when P7 reported the need to rapidly mute their smartphone, *"I have many situations where I'm in a meeting and the phone is charging and it starts ringing"* or for P13 who in a similar situation was *"driving*

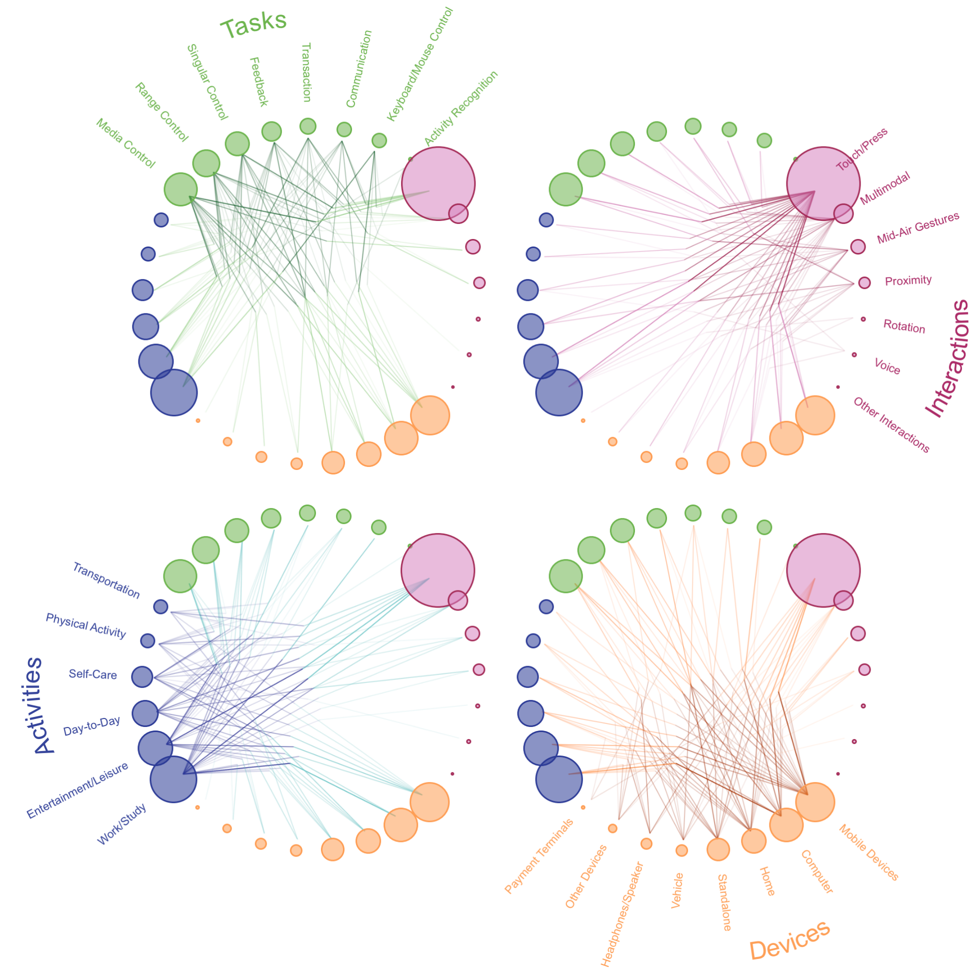

Fig. 3. Connections between themes for each of Tasks (upper-left), Interactions (upper-right), Activities (lower-left), and Devices (lower-right). The size of the vertices represent the percent of responses within a theme which included that code. The two-tone edges are done for easier viewing, while the higher the saturation of an edge represents more responses. To reduce complexity, all singleton responses were removed (i.e., the connections which only appeared once across 197 entries and thus reported by only one participant). We also provide a similar interactive visualization, in the form of an arc diagram, available here: https://smartringusagestudy.github.io/interactive_visualization/.

the car and the phone was ringing so I wanted to tap on the ring to decline the call". Throughout these situations, the smartring was considered, and imagined as, a device that could allow for fast and simple control of these secondary tasks, leaving the main form of control intact for the primary activities and associated tasks. Lastly, we note, while participants imagined using the smartring for individually unique combinations of devices and tasks, the majority of responses demonstrated the collective notion that a smartring would best be utilized for non-primary tasks and not as a full replacement to the device's full range of controls (e.g., a smartring would not replace all buttons on a TV remote control or a full fledged thermostat application on a smartphone).

5.4.2 Encumbered or Dirty Hands. Our participants provided detailed descriptions where there was a need to perform a task, yet their hands were occupied and/or dirty (21.3% of responses). The mock smartring was perceived to beneficially allow for task augmentation in these scenarios. As an example, P5 and P8 commented on a similar situation saying *"I wanted to open [the car] and get [the bags I was carrying] into the car while both hands were busy. The smartring can be used to unlock the car door"* (P5) or *"I am getting stuff out of my car and I want to lock my car using the ring"* (P8). Multiple participants noted that the smartring can be useful while cooking; as example P14 said, *"if you have got a tablet there and you don't want to touch it with your dirty fingers. With a ring I could scroll a recipe page"* and P1 said, *"I was looking at a recipe on my phone but with hands full of flour. It could be nice if I could unlock my phone with the ring, avoiding touching it"* (P1). Finally, another interesting situation was reported by P2, *"There were a lot of times where I was doing something with my left hand and I couldn't really swipe on my smartwatch [worn on right wrist]. I thought it would be really cool if you could interact [with the ring on right index finger] to scroll on the watch"*. Both the one-handed nature of smartring interaction and the placement of the ring located next to the thumb for interaction allowed for a perceived benefit when participants were performing tasks with their hands. This again shows that participants regard the availability of a potential smartring as higher than smartwatches and smartphones. Furthermore, they expected a smartring to be an always-available and single-handed interaction.

5.4.3 Unreachable Devices. Participants encountered moments where their personal devices were not immediately accessible or in reach, yet interaction was still desired (24.9% of responses). P6 stated, *"I realized that it was mostly that when I'm sitting or lying down, I wouldn't want to get up and control something. Some things left at a distance, these are the situations where I felt like it was very much desired to have a [smartring]"*. These situations often arose at home, where participants expressed a desire to use a future smartring to interact with household objects, appliances, and devices from afar. P8 said the smartring could be used when, *"finding your TV remote is brutal, and when you just need something like pause controls"*. P2 reported a similar situation where, *"I laid down in bed and forgot to turn off the light, it would have been so nice to use the ring to just shut off the light"* (P2). Often times the entries from participants recognized being in view of the device they wanted to control, yet it was still out of reach (e.g., sitting on the couch watching and wanting to control the TV or turning off the oven while sitting at the dining room table doing work). Here a future smartring, with its finger-worn and always available location, was seen as an ideal device to use so as to not interrupt the main task or to simply offer convenience to users.

6 DISCUSSION

Through our in-situ study, we showed the range of tasks, activities, devices, and interactions people felt future smartrings can provide benefit to. We also highlighted the advantageous usage scenarios of ubiquitous and connected smartring control perceived by our participants. Design considerations of future smartrings have been addressed by some prior works [12, 49], however, our results firstly show a structured expectation of users, derived from concrete and reported in-situ scenarios. By building upon prior works and our results, we derive design considerations to envision a future where a smartring can play a role within our daily lives. Furthermore, we discuss current challenges to inform future work.

6.1 Design Considerations and Current Challenges

6.1.1 Accommodate And Enable Effective Interaction Throughout A Variety Of Daily Usage Scenarios And Tasks. The spectrum of responses from our participants show the range of possible, and beneficial, augmentations of tasks the smartring could provide across all aspects of daily life. In fact, more than 40 unique combinations of tasks and activities were reported by our participants, highlighting the wide range of potential use for a smartring. Furthermore, the range of use was also apparent through the many devices, both smart and non-smart, within people's daily lives for which they feel a smartring could provide control. Interestingly, while participants reported a range of unique usage scenarios across their ongoing activities, the mock smartring was generally seen for non-primary tasks across participants which further often required simple, fast, and effective control.

We acknowledge that due to their form factor, smartrings may never satisfy all tasks proposed by our participants, as embedding all necessary components is not currently realistic. Yet, our findings importantly demonstrate that a smartring should not focus on a single-use case, thus should still attempt to enable use in a variety of daily tasks and activities to a fuller potential. Unfortunately, currently available commercial smartring devices typically restrain their users to a single purpose of use (e.g., the McLear RingPay which only focuses on NFC payments), and thus might prevent the adoption from a larger audience due their limited functionalities. Previous research has based knowledge finding in different areas, from hardware technicality (i.e., exploring different embedded sensors), e.g., [1, 26, 58], to novel interaction techniques (e.g., [14, 23]). Furthermore, prior works have also focused on the use of a smartring while mobile and/or encumbered [2, 4, 5, 13] which have begun to reflect increasingly natural usage scenarios. However, going froward, to allow for the range of responses concretely reported in-situ in our work, one challenge is to increasingly aim to merge these research areas in order to provide an optimal user experience across the desired multiple usage scenarios for potential smartring use.

6.1.2 Enable Touch, Mid-Air Gestures, and Proximal Interaction. While eliciting smartring interaction modalities, Gheran et al. [12] stated *"It's a touch input world"* when presented with the results that participants mainly invoked touch interactions. Our findings reaffirm this fact, as 59% of the reported desired interactions were Touch/Press; a modality that is preferred due to users' familiarity with such interactions [31]. Furthermore, our results highlighted that the large majority of interactions proposed (93.8%) could be captured through not only touch capacitive sensing, but also motion gesture recognition (e.g., using an accelerometer and gyroscope) and proximal interaction (e.g., NFC chip). While we controlled for placement of the mock smartring on an index finger, we note that the majority of proposed interactions could be performed on any of the hand's fingers. We also note that these interaction techniques, if all included, capture all tasks, activities, and devices reported. Thus, we recommend to support these multiple forms of interaction on a future smartring. This is in line with prior work that recommends the use of touch and mid-air gestures Gheran et al. [12], while we also recommend the inclusion of an embedded NFC chip in the smartring.

Furthermore, as touch input was mentioned in the majority of the interactions proposed, we note that expanding touch capabilities for miniature interaction surfaces could prove beneficial. Early work has begun in this research area, where Herath et al. [20] have successfully enabled continual slide and microroll gestures on a smartring. This allows for natural touch input to remain in place while also allowing for an increased set of interactive tasks to be facilitated. As devices become smaller, they bring with them challenges in interaction [3, 50]. The research community has previously expanded touch interaction capabilities (notably on smartphones or smartwatches) by exploring touch bezels (e.g., [33, 48, 59]), pressure sensing (e.g., [16, 38]), touch-based haptic interactions (e.g., [46]), or rolling gestures (e.g., [41]). Also, multimodal interactions, through touch and an additional input modality, have been studied as a way to extend the interaction vocabulary (e.g., [25, 57]). As smartrings are yet an increasingly miniature device, further exploration is needed for smartrings to expand their potential touch capabilities.

6.1.3 Prioritize Socially Acceptable Interactions. As expected, participants reflected on the need for *"subtle"* interactions (P2, P4, P7, P9). Surprisingly, participants were not always in favor of using mid-air gestures; P7 stated, *"if people are so close to me I might feel embarrassed to do some kind of mid-air gestures"*. While our findings suggest that participants proposed mid-air gestures, similar to Gheran et al. [12], we highlight that the activities and tasks for which to utilize these gestures typically occurred at home (79.4%) (e.g., downward wrist flick to turn on/off the lights). While touch interaction provides a more socially acceptable interaction modality, further investigation is needed to unveil the set of input interactions that can be socially acceptable to perform across daily life on a smartring, in public as well as in private settings.

6.1.4 Vibrotactile Feedback Was Preferred Over Other Output Modalities. Feedback on smartrings has been previously explored across a range of modalities such as through haptics [36], screens [14], and thermal displays [66]. Output modalities, such as the above mentioned, incur several disadvantages when incorporated on a smartring (i.e., low haptic sensitivity around the finger, mechanical constructs, limited output resolution, physically large and power hungry components) [49]. As such, we found it compelling that participants at times mentioned they envisioned the smartring providing them with feedback. In total, 13% of responses desired some form of output, with the majority being vibrotactile (72% of output suggestions) to display data (e.g., weather or biometric data), provide notifications (e.g., texts, emails, reminders, calendar events), or to alert a user at the end of a timer or alarm. For example, P5 suggested *"I would like a reminder to take a break from long hours of working on the computer"*. Our results further highlight that other forms of output (e.g., display, LEDs, audio) may be unnecessary, each reporting 8% or less of output suggestions. We postulate, similar to Shilkrot et al.[49], that due to the small form factor and finger-worn location of a smartring these output modalities were considered to be less noticeable, and thus less desirable. Instead, well-designed haptic cues for smartrings have the potential to provide a range of feedback (e.g., [18, 36]) and needs to be further explored for their viability in giving feedback under a number of scenarios.

6.1.5 Foster Intuitive Cross-Device and Cross-Application Connections. Our participants provided details about connecting the smartring with their surrounding devices; P3 mentioned, *"[it is a] ubiquitous input [device] for all devices around me"*. With an average of 5 devices across a wide range of 8 coded devices, reported for connected control by participants, a smartring was seen as beneficial for cross-device control, similar to the work by Shilkrot et al. [49], and further yet cross-application control. In fact, at times, the connections to devices and applications were even concurrent. For example, P4 mentioned that they wanted to *"turn all the devices to silent mode when a sudden meeting starts"*.

With a vision for ubiquitous and connected smartring control, and the array of devices required for connection, challenges arise in the pursuit of this goal. For the smartring to be used as a device to interact with all surrounding devices, fostering such connectivity is important yet not trivial. The need to allow simple and effective connections for the user includes the connection to a device but also the transition from one connected device to another. A main form of connected interaction proposed by participants, to switch devices to interact with, was through pointing directly at the desired device (P2, P3, P4); as example, P2 mentioned *"it would have been so nice to be able to just like point at [the light] or something... to shut off the light"*, and P4 said *"to point to something, just to connect with it and just to easily interact with things"*. Such forms of linking could benefit from the smartring having a spatial mapping of controllable devices in the user's vicinity. While smartrings are a relatively new technology, connected control has only been explored for other devices; notably in distributed or multi display environments, for example to transfer data from one device to another (e.g., [32, 43, 47]). While motivation can be taken from these works, little is known on how smartring connectedness could take place. Furthermore, how to connect and interact easily with devices when in different rooms (i.e., connecting the smartring with the oven to turn it off while being in the bedroom) is unknown. Investigation is needed to develop low-level protocols to facilitate cross-device connectivity with a smartring.

6.1.6 Smartring Versus Other Mobile Device Usage. In this early work, we aimed to capture all perceived beneficial instances of smartring use, so as to collect and be able to analyze broad usage scenarios, tasks, devices, and interaction techniques. Our results suggest of a specific area for smartrings, over their mobile-device counterparts, to allow for connected control and use throughout one's daily life. This can be seen through the benefit of enabled encumbered interaction without interventions needed (as needed in prior work [50]), many simple, discrete/binary, and rapid tasks desired that may provoke unnecessarily lengthy interaction on other smart devices, and control of other mobile-devices themselves. However, we do note that certain tasks such as broader media control and range control (e.g., temperature or brightness levels) remain to be challenging on a smartring; as such, other mobile devices may prove to be more beneficial and appropriate at this time. While participants may have been able to state their preference regarding the use of a smartring versus other mobile devices, this would have been hindered by the limited knowledge of what a smartring is currently capable of and will be capable of in the future. Preference in interaction and overall experience is greatly influenced by the input and output modalities built by researchers and practitioners. Thus, using the results from this work, indicating where smartrings were perceived for beneficial use, future work can begin to support these perceived use cases, and should then look to compare and contrast current and yet to be created novel smartring experiences (including input and output modalities for certain tasks, connected devices, and usage scenarios) with the use of other devices. Furthermore, defining a design space for smartrings that fully complements our usage of a range of devices is key to their future use and adoption.

6.1.7 Smartrings For Use As An Activity Tracker. Smartrings offer the potential for activity and health related metrics (e.g., heart rate and sleep quality) to be captured. The Oura Ring[8] accomplishes this and has seen success in commercial markets. Research has additionally validated, and thus shown the capability for, the use of smartrings when compared to dedicated hardware for sleep data collection [30]. While our mock smartring did not provide any such functionality, activity tracking was still suggested by three of our participants. We note, that while not related to connected control of devices, the capability for a smartring to perform activity monitoring, through increasingly powerful miniaturized sensors, offers a great option for those looking for non-bulky hardware. Furthermore, smartrings can be effective for interactivity while active [5]. Had this ability been conveyed to participants, we believe an increased number of standalone device responses would have been captured, potentially allowing standalone use to eclipse that of home appliance connections. While not fully captured here, future research can begin to explore the specifics of how activity monitoring can be enabled and used on a smartring. For instance, what interactions would be valid to start and stop activity tracking? How could feedback such as heart rate be conveyed to the user? How could sharing or casting of data to other devices be initiated and controlled? We postulate that through the above mentioned input and output modalities, much of this could be accomplished, yet largely remains to be explored.

6.1.8 Comfortable, Waterproof, Robust For Daily Usage And Designed Akin To A Typical Non-Smartring. Due to a smartring's finger-worn location, not only does it become a form of technology we own and use, but one that also provides a fashionable accessory and that could be personalized. As example, P7 noted *"I want [a smartring] to be comfortable first of all, and I don't want it to look very odd and want it to look fashionable"*. A smartring that does not conform to the notion of a non-smartring will undergo multiple levels of concern from users: 1) social acceptability of the design may prevent users from feeling comfortable wearing the smartring; P6 already noted, *"as a person who doesn't usually wear a ring, it was a little bit of a difficult thing to be able to you know wear the ring all the time"*. Overcoming the notion of a ring will already be difficult for some without the design drawing increased social attention, an issue currently being seen in the research of augmented reality glasses [17]; 2) cumbersome shapes or hardware components may alter grasps of objects or constrain movement. As the mock smartring was proposed to be used throughout daily activities, it must also allow for the un-interruption of these activities when not needed. This overall response by our participants is in line with the work of Shilkrot et al. [49] who recommend to create a comfortable and appealing form factor to aid in leading to the success of smartrings. Our findings support this recommendation but go further, in part due to the in-situ nature of

[8] https://ouraring.com/

physically wearing a mock smartring for a two-week period. In fact, participants noted that across the many day-to-day activities, and due to the finger-worn location of a smartring, they did not want to have to concern themselves with protecting the ring or worrying about damage (e.g., water and dust or impact with grasped objects). Furthermore, altering the way we typically use our hands, in the case of a non-robust smartring, is not acceptable when considering potential adoption of smartrings. Designers will need to place considerable attention on the smartring's form-factor along with the necessary embedded sensors, batteries, and hardware components.

6.2 Limitations and Future Work

Our small (N = 14) sample may limit the generalizability of our findings. Studying with a larger population would likely produce an increased set of diverse results; including, expanding on the tasks, devices, and interactions proposed for use through a smartring. We additionally note, that due to restrictions around the COVID-19 pandemic, daily life has been altered for many, although at the time of running this study health restrictions were loosened. We also note the study was conducted during a warm season, thus gloves and other coverings were not common or a limitation towards the generation of ideas. Additionally, while for 92.4% of responses, participants reported wearing the mock smartring, it was at times noted in the interviews that a participant would take off the mock device during certain activities (e.g., while sleeping, in certain social settings, showering, or while playing sports or working out). Thus, at times our responses may not capture all aspects of daily living. Finally, as with any elicitation study exploring the perceived use or capability of a new technology, limits do exist. Firstly, we may not capture all plausible usage scenarios due to participants not recognizing the capabilities or options they have. Second, and conversely, we may also over capture usage scenarios that are at times suitable for other devices. As a limitation in addressing this concern, our work did not ask of participants to think about their responses with regard to control devices, such as the use of a smartphone or smartwatch rather than a smartring. However, taking into account these limitations, our results remain to provide an examination of potential smartring usage and offers insight into the potential use cases and benefits that such a device could aim to support in future, as suggested by our participants.

As a first step, our work identified rich insights into the broad range of daily tasks, activities, devices, and interactions that could be facilitated through a prospective smartring. Future work is needed to explore the potential for interaction on a smartring (through both fundamental and novel interaction modalities as well as limitations or boundaries of current mechanisms for control), methods of connected control to allow for multi-device support, and appropriate output modalities. Ensuring smartring functionality across common daily occurrences (e.g., hands encumbered, mobile conditions, etc.) have to be increasingly considered. Furthermore, utilizing the findings of this work, we can now aim to further define the appropriate use of a smartring within our range of device usage. Our overarching goal has been to provide a better understanding of the potential for ubiquitous and connected smartring control. We envision the results of this study will encourage the research community in bringing in a new generation of personal computing, where smartrings can provide additional and seamless connected control.

7 CONCLUSION

This paper provides an empirical understanding of potential smartring usage throughout our daily lives, to expand upon the idea of what a future smartring design can and should incorporate for their broader adoption. Through an in-situ diary study with 14 participants over a two-week period, we reported on themes found within our collected data; including the tasks, primary activities, connected devices, and interaction techniques that people desired from a smartring. Our findings encompass a broad range of responses from individual participants within each theme, illustrating that smartring usage was desired through a diverse set of daily tasks, activities, and devices instead of being isolated for only a limited set of tasks. Furthermore, we highlight key perceived benefits of smartrings throughout our daily lives, such as for secondary (non-primary) tasks while multitasking, when hands are encumbered and/or dirty, and when devices are unreachable. Throughout, the smarting was mainly envisioned as an input device to perform simple and quick interactions. Finally, we highlight and provide design considerations as well as discuss current challenges of smartring connected control, laying a framework from which to build future research and smartring devices upon. We hope that this work can inform and inspire future researchers and designers, who focus on smartrings, to create an inclusive technology that supports daily living and a future of personal, ubiquitous, and seamless connected computing.

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