



# ADIO: An Interactive Artifact Physically Representing the Intangible Digital Audiobook Listening Experience in Everyday Living Spaces

Kyung-Ryong Lee

Grad. School of Creative Design  
Engineering, Ulsan National Institute  
of Science and Technology  
rgodragon@unist.ac.kr

Beom Kim

Department of Design, Ulsan National  
Institute of Science and Technology  
rakia@unist.ac.kr

Junyoung Kim

Grad. School of Creative Design  
Engineering, Ulsan National Institute  
of Science and Technology  
junyoung735@unist.ac.kr

Hwajung Hong

Department of Communication, Seoul  
National University  
hwajunghong@snu.ac.kr

Young-Woo Park

Department of Design, Ulsan National  
Institute of Science and Technology  
ywpark@unist.ac.kr



**Figure 1: ADIO (left).** The lever is pulled by user to show the amount of listening progress through the pendant's length and the title of the most recently played audiobook; ADIO is wirelessly linked (right) to the user's account on an audiobook streaming service on their mobile phone.

## ABSTRACT

Although audiobooks are increasingly being used, people tend to perceive audiobook experiences as 'not real reading' due to its intangibility and ephemerality. In this paper, we developed ADIO, a device augmenting audiobook experience through representing personal listening state in the form of an interactive physical bookshelf. ADIO displays a user's listening progress through a pendant's changing length and the user's digital audiobook archive titles. The

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

CHI '21, May 08–13, 2021, Yokohama, Japan

© 2021 Association for Computing Machinery.

ACM ISBN 978-1-4503-8096-6/21/05...\$15.00

<https://doi.org/10.1145/3411764.3445440>

result of our four-week in-field study with six participants revealed that ADIO provided proof of the user's listening-to, which brought a sense of reading and gave a trigger for recalling the listened-to audiobook content. Additionally, audiobooks' improved visibility reminded participants to listen to them, and ADIO's physical interaction allowed participants to form personal patterns for listening to audiobooks. Our findings proposed new methods for augmenting the audiobook listening experience at three stages and further implications for designing physical curation on users' digital archives.

## CCS CONCEPTS

- Human-centered computing; • User interface design;

## KEYWORDS

Audiobook, Data physicalization, Digital possession, Physical interaction

**ACM Reference Format:**

Kyung-Ryong Lee, Beom Kim, Junyoung Kim, Hwajung Hong, and Young-Woo Park. 2021. ADIO: An Interactive Artifact Physically Representing the Intangible Digital Audiobook Listening Experience in Everyday Living Spaces. In *CHI Conference on Human Factors in Computing Systems (CHI '21), May 08–13, 2021, Yokohama, Japan*. ACM, New York, NY, USA, 12 pages. <https://doi.org/10.1145/3411764.3445440>

## 1 INTRODUCTION

With the proliferation of digital streaming services for audiobooks and their advantages (e.g., time management, building critical listening skills), audiobook use has increased significantly [1, 28]. Along with this, digital audiobooks' mobility has provided a new reading format that enables people to read while doing other activities such as cycling, running, chores, or driving a car [5, 13]. However, audiobooks have several limitations. When listening to audiobooks, the user cannot control the narrator's voice, pronunciation, intonation, or tempo. This requires listeners to maintain their attention throughout the narration. Additionally, it is easy to become lost in other activities while listening to audiobooks, which makes it difficult for users to concentrate solely on listening [12, 23]. To this end, HCI researchers have conducted studies to complement audiobooks' limitations by providing technical support. The studies suggested ways to allow readers to actively participate in story-building [7], by automatically leaving bookmarks at moments of distraction [38], and by developing a smart bulb that changes color according to the mood of the narrator's voice for an emotion-driven listening experience [37]. Moreover, commercial audiobook applications (e.g., Audible, Storytel) are trying to overcome these limitations, focusing on enhancing the listening experience by creating unique sound effects, using the voices of authors and celebrities to narrate the books or creating short summaries of books that do not require a long period of concentration.

Despite the suggested features to enhance the listening experience, users often report that they cannot fully engage in audiobooks because of existing perceptions about reading a paper book. According to Müller et al., consumers' emotional attachment to paper books creates negative attitudes toward using audiobooks [32]. Specifically, the resistance toward audiobooks is due not only to consumers' attachment to reading, but also to the intrinsic value of physical paper books. Thus, to enhance the audiobook experience, it is necessary to understand the benefits of paper books' physical characteristics.

A paper book's physicality gives a reminder of the book's existence and personal reading state [9]. Moreover, the topology where a book is placed implies whether the book is currently being read [40]. Changes in the thickness of a paper book during and after a user's read naturally indicates a reading progress, which signals the continuity of reading [21, 40]. On the other hand, in terms of the audiobook listening experience, the lack of material properties means people are not reminded of the audiobooks' existence and their listening states. Thus, applying the positional and physical representation of the reading progress found in paper books to the audiobook listening process could improve the audiobook listening experience. In response to the above issues, HCI researchers have studied methods to combine paper books' physical properties with digital reading (i.e., e-books and audiobooks). Those studies

suggested ways to synchronize books and audiobooks by allowing users to jump to the correct section of an audiobook based on the page being read in a paper book [30], or by overlaying physical books with digital books by using augmented reality technologies [11]. Those studies focused on applying a physical method of reading a paper book to digital media. Augmenting the audiobook experience by maintaining audiobooks' digital listening method while reflecting paper books' physicality has rarely been studied.

Building upon the lessons from these previous studies, we captured the need to apply the advantages of the paper books' physicality to the audiobook listening experience. More specifically, we found a new design space for augmenting the intangible audiobook experience by applying positional and physical representations to indicate a personal listening state in everyday living spaces. To investigate the above research opportunity, we employed a research through design approach [45]. In this research, we developed ADIO (Figure 1), a form of an interactive physical bookshelf that displays a user's listening progress through a pendant's changing length and the user's digital audiobook archive titles. To explore how ADIO can support the audiobook experience, we conducted a four-week field study in six participants' living spaces. This paper makes two contributions. First, it introduces ADIO and its design process, both of which provide implications for integrating digital audiobooks into people's daily lives. Second, it describes the results of a four-week field study of ADIO, providing insights into how the physical representation of an individual's listening state enriches the digital audiobook listening experience.

## 2 ADIO'S DESIGN, RATIONALE, AND IMPLEMENTATION

### 2.1 Positioning Digital Audiobook Listening Experiences in Everyday Living Space

ADIO's design aims to complement audiobooks' invisibility and intangible, ephemeral listening experience. According to Odom et al., supporting easy access for virtual possessions is essential to integrate digital archives into everyday life [34]. Augmenting information on everyday physical objects could deliver information to users in a familiar way as well [11]. In line with previous research on virtual possessions and information physicalization, we considered ways to enable audiobooks visible into users' living spaces.

We first investigated what kinds of everyday artifacts would best represent users' digital audiobook archives. Previously, HCI researchers have explored ways to represent individual's reading state on the books' spine stored in the bookshelf [4, 26, 29]. Among several everyday objects, we expected a bookshelf would be a great medium; a shelf is a space for storing and selecting books to read in one's living space. Simultaneously, the bookshelf represents the reader's interest in books and includes the history of the person's reading experiences. Books facing outward on a bookshelf remind their owner of their existence, presence, and availability [9, 18]. Thus, we focused on ways to locate audiobooks inside the living space by borrowing the shape of a bookshelf. During the ADIO design process, we mainly considered two forms: a built-in bookshelf type (Figure 2a) and a standalone type (Figure 2b). The major difference between the two types is whether the device is designed



**Figure 2: ADIO design process: a–e) Ideation sketches. f) Variations of the display and frame configuration. g) Final design.**

to be installed and fixed inside the bookshelf or moved independently. We decided to develop ADIO as a small bookshelf-shaped standalone device to allow users to place the device in their living spaces freely.

We carefully chose what sort of information to display among various audiobook metadata. As a result, we selected book titles, authors, and covers, which are considered important when choosing a paper book [15], as well as the narrators, who essential in the audiobook experience (Figure 3, right). ADIO's vertical display references a book's spine, which shows basic information about a book. Lastly, ADIO's outer frame was designed in the form of bookends to enable users to store and rest their paper books against ADIO (Figure 2f, 2g's bottom). This was to provide a similar sense of reading a paper book to the audiobook listening experience, which might lower user's mental barriers toward audiobooks. Through these design elements, we intended to allow ADIO naturally integrated into the user's living space harmoniously with paper books.

## 2.2 Physical Representation of Personal Listening States

We have set our target as people who are interested in listening to audiobooks but feel that it is difficult to start or listen consistently in their daily routines. According to data physicalization studies [19, 42, 44], the existence of personal data in everyday spaces makes data more accessible to people and enables self-reflective practices. Thus, we designed ADIO that creates positional and physical cues of one's listening status, supporting him/her to opportunistically encounter audiobooks, listen to them, and monitor his/her listening progress.

Based on this understanding, we devised three methods to physically convey the personal listening progress. First, a flip counter mimicked turning pages from one side to another (Figure 2c); second, a tape recorder showed the accumulated listening time through reeling tape (Figure 2d); third, the pendant's changing length was inspired by ribbon bookmarks (Figure 2e). Of these types, we first

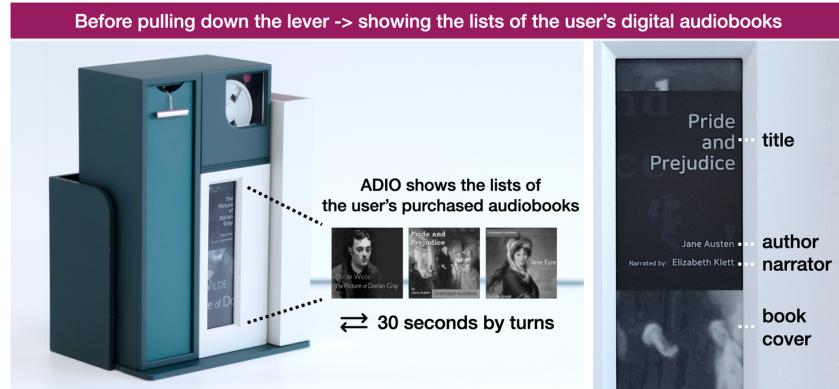
abandoned the flip counter model, which had limited display ability due to a fixed amount of pages. Then, we selected the changing pendant length display, which could show the user's listening progress at a glance, even at a distance. By combining the third type's tape reel with the pendant design, we wanted to let ADIO provide the sense of accumulating audio data. Additionally, to allow users to check their listening progress, we implemented a book-shaped lever (Figure 2g), adapting the book-selecting posture of tipping books to browse what to read. The final ADIO design follows in Figure 2g. As audiobooks' mobile advantages significantly affect listening experience [12], we let users keep listening to audiobooks using their smartphones and streaming services. We focused on providing physical feedback about the listening progress after listening to audiobooks. We chose the most popular audiobook streaming service available on a mobile platform in the country where this research was conducted, Naver AudioClip [2].

## 2.3 Interaction of ADIO

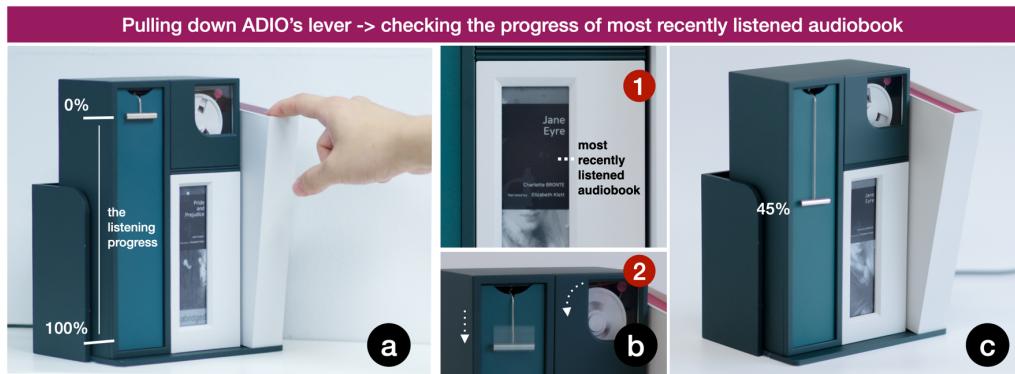
ADIO consists of an e-ink display showing audiobooks, a pendant with a rotating disc, and a book-shaped lever (Figure 2g). Interaction with ADIO depends on whether the lever is pulled down.

**2.3.1 When the Lever is not Pulled.** When the lever is not pulled, the e-ink display shows all the recently purchased audiobooks, one by one, every 30 seconds (Figure 3). In this state, the pendant does not move to show any audiobook progress.

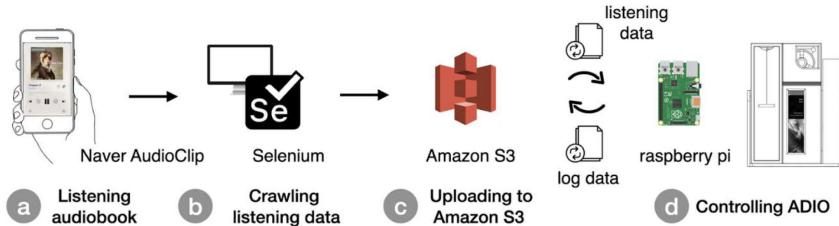
**2.3.2 Pulling the Lever To Check Progress In The Most Recently Played Audiobook.** When the user pulls down ADIO's lever (Figure 4a), the most recently played audiobook is shown on the e-ink display (Figure 4b-1). Then, as the disc rotates, the pendant descends to a position that represents the progress in the audiobook (Figures 4b-2, 4c). The user can also check another audiobook's progress with an additional clicking of the tilted lever. If there is no more input for 30 seconds in this state, ADIO displays the most



**Figure 3:** Before pulling down the lever, ADIO shows all of the user's digital audiobooks in a 30-second rotation.



**Figure 4:** a) Pulling the lever. b-1) Checking the title and cover of the most recently heard audiobook. b-2) The pendant descends to match the listening progress of the audiobook. c) Stopped pendant showing listening progress. (about 45% of the audiobook's length)



**Figure 5:** Developed software structure of ADIO.

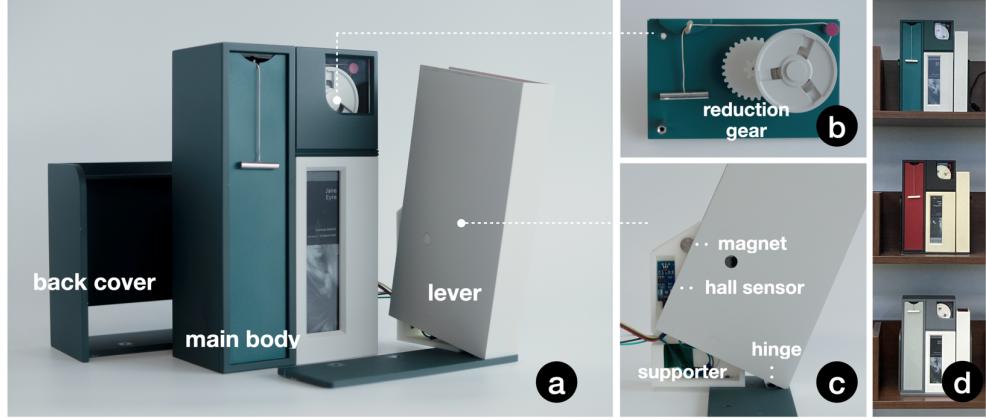
recent audiobook and its progress again. Users can see completed audiobooks only when the lever is up. ADIO automatically updates the user's listening states every 5 minutes from their audiobook streaming service account.

## 2.4 Implementation

**2.4.1 Software.** We used Selenium WebDriver to obtain users' audiobook listening data from Naver Audioclip (Figure 5a, 5b). We crawled the title, author, reader, and cover image URL from each user's account and downloaded the book cover images from the URLs. These data were uploaded to Amazon S3 buckets in

JSON and PNG format (Figure 5c), then downloaded back to the Raspberry Pi board embedded in the ADIO unit (Figure 5d). Data crawling was conducted every 3 minutes, and ADIO retrieved data every 1 minute from Amazon S3. This way, participants could confirm the changes in their listening progress within 5 minutes.

**2.4.2 Hardware.** ADIO mainly consists of three parts: the main body, back cover, and lever (Figure 6a). To detect a user tilting the lever, (the downward pull action) we used a hall sensor and a magnet in the inner support (Figure 6c). A small hinge is attached to the bottom of the lever to implement stable movements.



**Figure 6: Detailed structure of ADIO:** a) The three main parts of ADIO. b) The gearbox connecting the pendant and disc. c) The lever's structure with the supporter recognizing the state of the lever. d) Three ADIOS with different colors.

Additionally, we carefully decided on the speed at which the pendant's length changes and the speed of the disc rotation to give feedback that is neither too fast nor too slow when participants check their listening levels. A reduction gear was used between the pendant's gears and the gears of the disc (Figure 6b). The reduction ratio is 9:1; this allows the pendant's length to change nine times slower than the disc's rotation. We inserted a magnet inside the pendant and used a hall sensor from the main body (Figure 6a) to recognize the pendant's position. A step motor was used to control the pendant's length.

### 3 USER STUDY

We conducted a field study over four weeks in users' everyday spaces to look deeply into how ADIO affects the audiobook listening experience. We wanted to identify 1) how ADIO changes the current listening experiences, creating new situations and practices for listening audiobooks through the positional and physical representation of one's listening states in living spaces; and 2) how ADIO could complement and augment the intangible listening experience based on the use cases obtained.

#### 3.1 Method

**3.1.1 Participants.** We recruited participants by conducting a brief online survey on audiobook listening experiences along with other reading patterns and habits. We selected six young adults (ages 22–35, 2 males and 4 females, P1–P6) among 27 applicants. Our criteria for selecting these participants were as follows:

1) three people who had listened to more than one audiobook in the last six months ( $N = 3$ , P1–P3), and 2) three people who had not listened to audiobooks, but had read more than two books (including e-books) in the past six months. These criteria ensured we selected people interested in reading who could continue to listen to the audiobooks during the experiment ( $N = 3$ , P4–6). To bring out as many diverse experiences as possible, we included both applicants who had listened to audiobooks and those who had no audiobook listening experience within the last six months. To prevent a lack of preferred audiobook content and the situation

of avoiding listening to audiobooks due to the cost, we ensured each participant had at least three preferred audiobooks in Naver Audioclip and provided participants with a budget for purchasing audiobooks in advance. Participants' detailed information is as follows.

**P1: Freelance graphic designer (24, female).** She usually listens to audiobooks in the background when she is working or before going to bed. However, she often listens to audiobooks repeatedly because she has difficulty remembering their contents well.

**P2: Environmental researcher (35, female).** She listens to audiobooks occasionally on business trips, but does not usually listen to them. She is very interested in reading, but she is busy with her work.

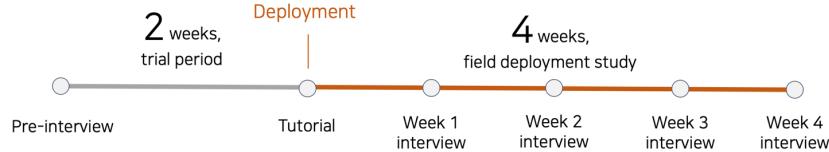
**P3: UX design researcher (26, female).** She reads paper books and e-books, and also listens to audiobooks. She toggles between listening to several audiobooks at a time that are focused on only her areas of interest.

**P4: Freelance visual designer (26, female).** She usually reads paper books while she commutes. She expects to listen to audiobooks before falling asleep in her bed.

**P5: Master's student in neuroscience (25, male).** He usually uses his commuting time to read e-books. He continuously checks how much he has read and cares a lot about it. As for his audiobook experience, he finds it difficult to remember the audiobooks' contents.

**P6: Web developer (24, male).** He usually reads e-books on his iPad during his commute. He prefers the digital functions of e-books (URL access, real-time search). He has experienced audiobooks once through YouTube.

**3.1.2 Two-Week Audiobook And Trial Period Prior to ADIO Deployment Study.** To familiarize participants with the experience of listening to audiobooks through Naver Audioclip, we provided a two-week trial and baseline period before deployment, allowing all participants to focus on the audiobook experience in advance without ADIO. The entire study took six weeks, including these two weeks for the trial period and the four weeks for the field deployment period using ADIO (Figure 7).

**Figure 7: Overall timeline of field study.****Table 1: Summary of weekly interview questions.**

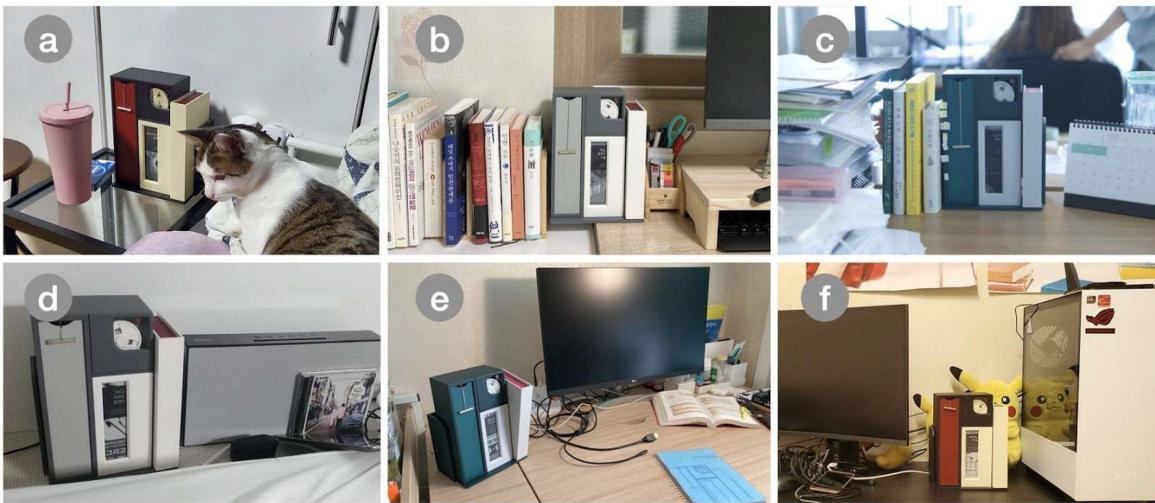
Interview contents	
Week 1	The circumstances in which participants used ADIO. The experience of physically checking listening progress. The place where ADIO was deployed and reasons why.
Week 2	Overall use pattern of ADIO. Following thoughts after using ADIO. Changes in listening patterns.
Week 3	Changes in ADIO use patterns compared to weeks 1 and 2. Different aspects from previous experiences listening to audiobooks.
Week 4	Significant changes over the past four weeks. How ADIO affected the audiobook listening experience. Different aspects of the previous audiobook listening experience without ADIO.

**3.1.3 Deployment, Interview, Data Collection, and Analysis.** We held 30-minute pre-interviews on the first day of the trial period. Pre-interviews included 1) an introduction of the user study, 2) interviews about paper book reading and audiobook listening experiences, and 3) data crawling tests that accessed the users' Naver Audioclip accounts. Through technical testing, we ensured there was no problem with collecting participants' listening data. We connected ADIO to participants' accounts and set the Wi-Fi information of the deployed personal living spaces. On the first day of deployment, we provided 30-minute tutorial sessions to help participants learn all of ADIO's functions and uses. We instructed participants to place their ADIOS anywhere they wanted

in their living spaces, and to move the devices by themselves during the study. Additionally, we used VNC remote access software to enable troubleshooting for operational problems during the study.

We conducted interviews weekly, and each interview took about 40 minutes. We fully transcribed 1,154 minutes of interview recordings. All interviews were semi-structured. Details of the interview questions are summarized in Table 1.

To record changes in the participants' audiobook listening patterns, we collected the titles of the audiobooks they listened to, the amount of time they listened to them, and the times at which participants listened to them. We also recorded timestamps at every

**Figure 8: ADIO in situ: a) P1's ADIO, kept on her bed table. b) P2's ADIO, placed on her desk along with paper books. c) P3's ADIO, placed on her office desk. d) P4's ADIO, deployed beside her bed with other hobby materials. e) P5's ADIO, placed on his desk. f) P6's ADIO, placed on his desk.**

**Table 2: Total frequency of interactions and time listening to audiobooks during the four-week deployment study.**

	P1	P2	P3	P4	P5	P6	Total
Total listening time (min)	984	256	452	813	498	633	3636
Total attempts to start listening to audiobooks	114	47	46	105	35	41	388
Total number of completed audiobooks	6	5	6	3	3	5	28
Total number of times ADIO's lever was pulled to check listening progress	121	42	49	49	59	40	360

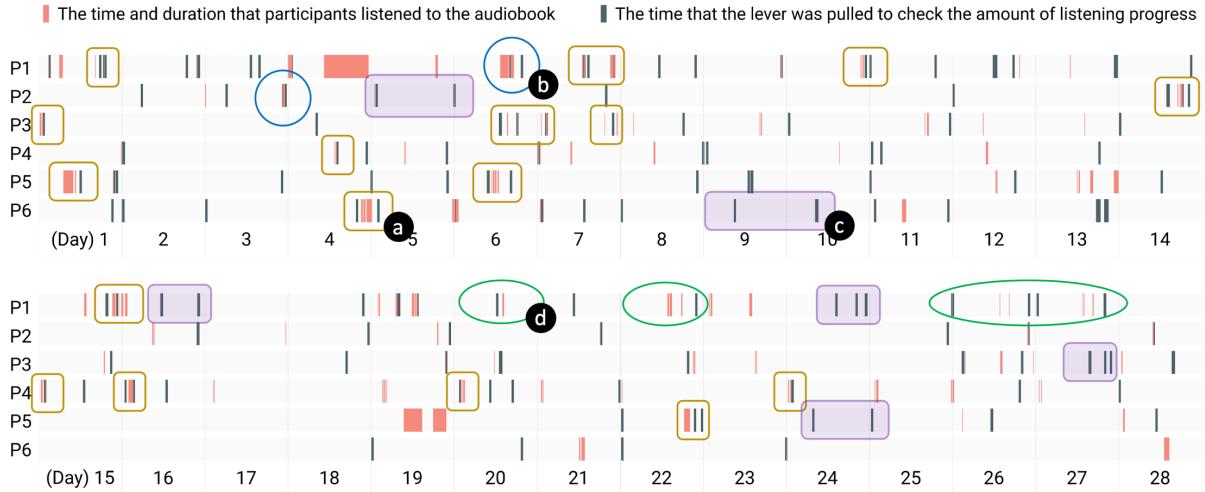
moment of interaction with the ADIO to keep track of changes in ADIO usage patterns (Figure 9). For four weeks, the six participants listened to a total of 28 audiobooks for 3,636 minutes, with a total of 360 interactions with ADIO (Table 2).

The interview recordings were transcribed, and three co-authors generated open codes right after each interview for four weeks. By using those codes, we went through an iterative affinity diagramming process, and created a thematic connection of the open codes, resulting in three large clusters as follows: 1) influence of the physical representation of one's listening state on the audiobook listening experience, 2) ADIO's presence in the environment and its effect, and 3) personal patterns of ADIO usage for listening to audiobooks. Afterwards, we added two researchers to extract meaningful sub-themes and related statements by reviewing open codes in each cluster, resulting in the creation of six subgroups. By applying

a triangulation of descriptive quantitative analysis of the usage logs and the interviews, we detailed how ADIO supported participants' audiobook listening experiences. Last, we tried to identify findings more distinct to ADIO in comparison with previous studies.

## 4 FINDINGS

We were able to confirm moments when the participants checked their listening progress using ADIO. Most participants checked their listening progress before starting to listen to audiobooks and right after they stopped listening to them (Figure 9a, blue squares). Besides, we could see that two participants (P1 and P2) remarked that they pulled the lever to check the pendant's changing length while listening to audiobooks (Figure 9b). P1 mentioned, “(Because) I wanted to see that the audiobook was playing. When I read a paper book [she pretended to open a paper book], I can see how much I have



**Figure 9: Usage log data of six participants over four weeks:** a) Participants checked their listening progress before starting to listen to audiobooks and right after they stopped listening to audiobooks (brown squares; happened a total of 25 times by all participants for four weeks). b) P1 (day 6) and P2 (day 3) listened to audiobooks, and during playback, they pulled the lever to check the amount of listening progress. c) All participants continued to check their listening progress even when they did not listen to audiobook (purple squares). d) The lever was pulled first and P1 went out and listened to the audiobook on day 20. After the day, she listened to the audiobooks outside first and checked her duration of listening after returning home on days 22, 26, and 27.

*read directly, but listening to the audiobook was vague...*" Moreover, we could confirm that ADIO provided an additional opportunity for participants to check their listening progress when they came back home, which was difficult to capture when they listened to audiobooks outside. P2 noted, "*In fact, when I listen to an audiobook in the car or outside, it just ends, and I do not check the progress. But now, I can check the progress when I get back home.*" Based on the frequent and easy access to their listening states, we were able to discover the following findings.

## 4.1 From Ephemeral to Archived Listening Experience

**4.1.1 Giving a Physical Proof for Listening to Intangible Audiobooks.** Five participants noted they felt the audiobooks and listening experience existed in real world, rather than disappearing in the digital world when they recognized the length of ADIO's pendant increase. P4 mentioned, "*Sometimes I felt really empty after listening to audiobooks. I felt that they were just information and stories floating on the Internet. Now, as the floating data is captured by the ADIO, it proves that I have read it in the real world rather than in the Internet world. It makes me think I 'read' it rather than 'heard' it.*" She continued, "*When I listened to it [an audiobook] through only the app, I recognized it as a digital file, but now when I see the pendant, I think, 'Oh, I read a lot of books.'*"

P6 stated, "*To be honest, showing the progress can be replaced by displaying the numbers [percentage complete] on the e-ink display. But the fact that the pendant doesn't come down digitally, but it comes down when I pull the lever—That makes me think 'I really own this book.'*"

On the other hand, four participants were disappointed that finished audiobooks' progress was not shown in ADIO any longer because ADIO only showed the progress of an ongoing audiobook and the finished titles on display when the lever was not pulled. P1 mentioned, "*I was really sad. It felt like as soon as I finished the book, I just put it on the bookshelf without looking back.*" All participants mentioned they wanted to save the completed audiobooks' progress in ADIO. The unexpected disappearance of finished books' listening progress in ADIO revealed the need to preserve the digital audiobook experience not only during listening, but also after completing the listening by representing the finished status.

**4.1.2 Recall Audiobook Content By Referencing Physical Cues.** Throughout the interviews, we confirmed that participants ( $N = 4$ ) recalled the content they listened to when checking their listening progress through ADIO. At first, P5 pointed out the difficulty of remembering audiobooks' contents compared to reading an e-book. He explained, "*I can underline and take notes to remember the contents when reading e-books. But I can't do those things when listening to audiobooks, and the only thing I could do was pause the audiobook for a while to take time to think about the contents. But then I felt that those were forgotten immediately.*" He continued, "*However, when I pull down the [ADIO's] lever, I think I'm trying to remember what I heard. After listening to an audiobook before bed, I checked the progress the next morning using ADIO and asked myself, 'What did I listen to last night?' Then I remembered things like, 'Oh, there were some wines, and how the wine got the name...' [he listened to an audiobook related to wine].*"

Two participants (P1 and P5) tried to remember the audiobooks' contents by matching them with the physical positions of the lengthened pendant. P1 noted, "*I think it [the pendant] comes down as much I learned from the audiobook. I mean, it seems to show how much I remember the contents of the audiobook. So I think it's fun. I tried to check the progress [position of the pendant] because I can see where the content I listened to is located in the audiobook.*" P5 stated, "*When I looked at the cover [of the finished audiobook] through ADIO, the situations when I had checked the listening progress with the pendant and recalled the contents crossed my mind. I remember the contents that I listened to when the pendant was placed at about 40% and 60%.*"

With ADIO's support in remembering the audiobook's contents, P1 explained it affected her listening pattern and perception about reading. She usually toggled between playing several audiobooks repeatedly in the background while working or before sleeping. After using ADIO, she solely focused on listening to one audiobook and tried to remember its contents. As a reason for the change, P1 stated, "*Well... It's kind of hard to say exactly since I was using the product [ADIO]... it feels like one more process is added in listening to audiobooks. In other words, I feel like I'm recording and tracking how much I've listened to the audiobook and remembered throughout the day.*"

According to previous studies [9, 35], the placelessness and invisibility of virtual possessions has the advantage of being accessible anywhere, while also preventing people from recognizing where any data is stored. Those studies suggested that it was important to make virtual possessions visible for integration into everyday life. In line with the findings of those studies, we confirmed that the everyday existence of digital audiobooks and personal listening data could be a physical medium connecting the on- and offline audiobook experiences. Additionally, we confirmed that the accumulated length of ADIO's pendant became proof of the user's listening, which brought a sense of archived listening. It also provided a trigger for recalling the audiobook content. From this, physical representations of personal listening states could be a way to complement the intangible audiobook listening experience.

## 4.2 Connecting User's Will to Listening to Audiobooks through Physical Triggers

**4.2.1 Increased Visibility of Personal Listening States Reminds Users of the Purpose of Listening to Audiobooks.** All participants mentioned that using ADIO was a continuous reminder that they were listening to audiobooks. P6 mentioned, "*This [ADIO] feels like some kind of shelf structure, it feels like a bookshelf on my table... it tells me, 'read me,' because it [the e-ink display] keeps fading in and out... It became like a habit to check which book I was on and how much I had listened to. Because if I don't keep checking these things, I might forget that I'm currently listening to audiobooks.*" We also confirmed in P6's log data that he continued to check his listening progress even on days that he did not listen to audiobooks (Figure 9c). Three participants, including P3, reacted positively about how ADIO provided reminders for listening to audiobooks. P3 mentioned, "*[ADIO reminders] It's not a burden, more like 'it's a time to read a book.' It's a reminder of the desire to acquire knowledge through reading.*"



**Figure 10:** Sticky notes on ADIO represent P3’s listening history. (left) The second week of her field study; (right) The last week of her field study.

P2 was concerned that she did not read enough in her daily routine because she was busy with her 9 am to 10 pm work schedule. Regarding this, she noted, “*It is rather hard to read paper books if I do not make myself extra time for that. But also, there was a disadvantage of listening to audiobooks, because I even forgot whether there was an application in my mobile phone.*” On the other hand, after using ADIO, P2 was able to continue listening to audiobooks with the reminders ADIO provided. She stated, “*Now I just put my earbuds on and listen to audiobooks whenever I have spare time. I think it complements both the disadvantages of paper books and audiobooks.*” In response, P2 referred to ADIO as a “reading assistant” and explained that it helps not only listen to audiobooks, but in general, it also helps overall reading activity. In follow-up interviews, we discovered that P2 listened to audiobooks in her spare time, which had previously been used to consume other kinds of media (e.g., driving while listening to music, watching YouTube videos while waiting for job-related materials).

In line with previous studies’ findings [3], we were able to see that the increased visibility of users’ listening states could remind them of the purpose of listening to audiobooks, which was participants’ desire to read more. This motivated the participants to listen to audiobooks in their daily lives.

**4.2.2 Forming Personal Approaches to Using ADIO’s Physical Interaction for Listening to Audiobooks.** We noticed that participants formed their own ways to utilize ADIO’s physical interaction for listening to audiobooks. First, P2 set a short-term goal on the pendant’s physical length. She mentioned, “*I set a goal, such as a minimum amount of reading before bed. I marked a certain point of the pendant’s length and would listen until it touched that mark before bed.*” P1 utilized the physical action of pulling down ADIO’s lever to promise herself to listen to audiobooks outside. P1 stated, “*Before, I pulled the lever to check my progress after I was done listening to an audiobook. But now (in her third week of field study, 9d), I pull*

*down the ADIO lever before going out and check the changes in the audiobook’s progress after coming back home. It feels like a personal promise about ‘I will listen to this book from now on.’ Since I pulled down that [lever] and came out, it made me think about listening to audiobooks once more [from outside] in a situation during which I usually listened to music.*”

On the other hand, P3 pointed out that as ADIO only showed the current listening status, she could not check her past personal listening history. To compensate, she attached sticky notes beside the pendant’s position to record her listening history (Figure 10, right). She mentioned, “*I used sticky notes because I wanted to check how much difference there was compared to my last progress.*” Also, P3 referred to ADIO and the sticky notes as a “lighthouse” that reflected her audiobook listening pattern. She explained that it helped her to listen to audiobooks continuously in her daily life.

The presence of significantly fewer physical restrictions acts as an advantage in listening to audiobooks [12]. Nevertheless, our participants devised a creative physical interaction with ADIO (e.g., sticky notes to check the progress of reading) for planning audiobook listening. Based on these results, there is a need for further discussion about how to augment the intangible audiobook listening experience with physical interactions.

## 5 DISCUSSION

Through ADIO, we explored how to complement the intangibility and ephemerality of the digital audiobook listening experience. With the increased consumption of digital content, not only digital audiobooks, but also meaningful digital archives are significantly created. In this regard, HCI studies [10, 14, 33, 36] have highlighted the importance of integrating personal digital archives into people’s everyday lives, and they require further research on the specific ways for blending the digital collections in living spaces. In this section, we discuss the considerations for integrating digital

possessions into our daily lives through physical curation on digital archives.

### 5.1 Toward Augmenting Audiobook Experience from Pre-Listening to Post-Listening

During the analysis of findings, we could find out new design spaces for augmenting the audiobook listening experience at following three stages. These considerations provide opportunities for future HCI research to design interactive artifacts for augmenting audiobook experiences, further showing potentials for designing user experience of other types of digital audio content (e.g., Podcasts, Duolingo [31], Internet radio), which was rarely captured and easily lost despite its high value.

**Pre-listening:** Providing continued awareness of the audiobooks' existence is significant in motivating users to listen to the audiobooks. In this respect, having a tangible encounter to represent the intangible listening states in daily living spaces could aid users in beginning to listen to audiobooks. This could complement the lack of material representation of audiobooks and be the basis for starting audiobook listening. At this point, physical interaction can be provided for planning to listen to audiobooks. These physical triggers can help users start listening by encouraging them to plan their next listening at a specific time or in a specific context, where they did for reading a book (e.g., pulling the ADIO's lever for promising next audiobook listening and finding a quite space and time for concentrating on listening as P1 reported).

**During-listening:** At the same time, it is essential to show the qualitative aspects of a personalized listening experience. In our user study, participants demonstrated the need to see their personal listening behaviors on the ADIO units (e.g., using bookmarks/memos for their thoughts or favorite phrases). Visualization of these behaviors might augment users' awareness of interacting with their digital listening and increase ownership of digital audio content [39]. Furthermore, providing room for participants to select personally meaningful data to be visualized is crucial. For instance, not only the listening states, but also providing users the opportunity to conduct special markings to revisit a certain part in the chapter. While listening to audiobooks, these manual efforts taken to curate and manage their digital archives could increase the intimacy with their data [42]. In addition to recalling the audiobooks' contents, the listening progress's physical accumulation is a cue for connecting fragmented listened instances. Due to the lack of methods for remembering previous stories, assisting in remembering what users have heard can support the continuous audiobook listening experience.

**Post-listening:** Lastly, as our participants noted, acknowledging the achievement of finished audiobooks may strengthen the experiential quality. From ADIO's participants' needs to preserve their accumulated digital audiobook experience, we could confirm that it is necessary to provide a reward when the users complete listening to an audiobook. For this, just as paper books and bookshelves show their reading history [9], it is necessary to explore ways to express audiobooks' listening history in personal digital accounts in everyday spaces. This provides an opportunity to revisit a finished audiobook in daily life. Furthermore, this listening history

physical exposure can serve as a showcase for self-representation to oneself and to those around them. This may provide users with a sense of accomplishment and encourage self-reflective practices as they use their data to reminisce or manage their listening behavior [6].

### 5.2 Blending Digital Methods of Consumption and Physical Methods of Curation

Many HCI researchers have studied methods of materializing digital content to complement its lack of tangibility in consumption [22, 24, 27, 41]. Those studies highlighted how the physical means of consuming digital content improve the lack of possession, emotional attachment, and social interaction. On the other hand, Gupta et al. addressed that even among users who enjoy physical experiences, digital consumption was still more frequent because of its accessibility and its affordance of a vast amount of data [11]. In this, we found new design opportunities for physically supporting users while maintaining digital media consumption.

One way could create a complementary relationship between digital consumption and physical curation. In the ADIO field study, participants used their mobile applications to listen to audiobooks. At the same time, as ADIO's bookshelf-shaped design allowed users to put their paper books next to ADIO, it acted as a visual reminder to recall the book-reading experience. In that way, ADIO could reduce emotional resistance to audiobooks while providing a space that blended the reading experience of paper books and audiobooks.

In addition, when providing physical engagement with digital possessions, it is necessary to consider the spatial characteristics of the place and things around where the digital archives are stored. According to Manches et al., objects can be located in three dimensions, with their position relative to other objects, the user, and the environment [25]. Since the digital property is placeless [35], the spatial placement of digital possessions can be affected by its location character depending on the location and objects placed around it. During our user study, participants who wanted to receive more reminders for listening to audiobooks placed ADIO within their range of sight and in more accessible spaces (e.g., on a desk that must be passed by where they put their wallet or smartphone), while others located ADIO near other materials (e.g., next to the speaker, paper books, or a tablet PC for drawing; see Figure 8). In line with previous study [8], these instances helped us understand how the positional characteristics of the space for curating digital archives can affect the experience by reflecting personal ways of consuming digital media.

Moreover, we needed to consider how to suggest physical interaction techniques that supported digital consumption. ADIO study participants mentioned the desire to connect ADIO with other smart devices in their homes (e.g., using a smart light bulb to create an audiobook listening atmosphere) when ADIO's lever was pulled down. This kind of physical interaction could be associated with the surrounding environment to provide an atmosphere that encourages digital media consumption. As previous studies [11, 16, 17, 43] stated that physical interaction allows us to treat invisible digital objects as a physical experience, this approach could enhance the intangible experience of consuming digital media.

ADIO's morphological, locational, and environmental physical restrictions became the basis for applying the participants' existing reading habits to the audiobook listening experience. Thus, rather than replacing digital ways of listening, it is important to consider how physical reading might be used alongside digital listening. Furthermore, this might further be applied for designing interactions that maintain the strengths of digital methods of consumption and physical methods of curating users' digital possessions [20, 34].

## 6 CONCLUSION

We introduced ADIO to explore how the intangible and ephemeral experience of listening to audiobooks could be improved by creating positional and physical cues for an individual's listening status. ADIO's design allowed users to opportunistically encounter audiobooks and monitor their listening progress through physical representations in everyday living spaces. Through the design iterations, we carefully devised a way to integrate checking one's listening progress and displaying users' audiobook archives in the form of an independent bookshelf. The four-week field study showed that ADIO became a physical medium connecting the on- and offline audiobook experiences. ADIO's intervention in the process of audiobook listening enabled users to confirm and recall their progress through physical proofs, further giving a sense of archived listening. We also found the increased visibility of personal listening states reminded participants of their reasons for listening to audiobooks. Moreover, ADIO's morphological and interactive triggers helped users form personal approaches to continue audiobook listening. Based on these findings, we propose new methods for augmenting the audiobook listening experience at three stages; pre-listening, during-listening, and post-listening. In addition, there are further opportunities to design interactions for blending the digital consumption and physical means of curating users' digital archives.

## ACKNOWLEDGMENTS

This work was supported by the NRF-2020R1F1A1054047 and Next-Generation Information Computing Development Program NRF-2017M3C4A7083534 through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (MSIT). We appreciate the reviewers' constructive feedback on this paper.

## REFERENCES

- [1] Audio Publishers Association. 2020. 2020 Consumer 2019 Sales Surveys Announcement. (2020). <https://www.audiopub.org/uploads/pdf/2020-Consumer-Survey-and-2019-Sales-Survey-Press-Release-FINAL.Pdf>
- [2] Audioclip. Naver. <https://audioclip.naver.com/>
- [3] Ana Caraban, Evangelos Karapanos, Daniel Gonçalves, and Pedro Campos. 2019. 23 Ways to Nudge: A Review of Technology-Mediated Nudging in Human-Computer Interaction. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19). Association for Computing Machinery, New York, NY, USA, 1–15. DOI: <http://dx.doi.org/10.1145/3290605.3300733>
- [4] D. Crasto, A. Kale, and C. Jaynes. 2005. The Smart Bookshelf: A Study of Camera Projector Scene Augmentation of an Everyday Environment. In 2005 Seventh IEEE Workshops on Applications of Computer Vision (WACV/MOTION'05) - Volume 1, Vol. 1. 218–225.
- [5] Lavinia Egidio and Marco Furini. 2006. From Digital Audiobook to Secure Digital Multimedia-Book. *Comput. Entertain.* 4, 3 (July 2006), 5–es. DOI: <http://dx.doi.org/10.1145/1146816.1146825>
- [6] Chris Elsden, David Kirk, Mark Selby, and Chris Speed. 2015. Beyond Personal Informatics: Designing for Experiences with Data. In Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15). Association for Computing Machinery, New York, NY, USA, 2341–2344. DOI: <http://dx.doi.org/10.1145/2702613.2702632>
- [7] Marco Furini. 2007. Beyond passive audiobook: How digital audiobooks get interactive. In 2007 4th IEEE Consumer Communications and Networking Conference. IEEE, 971–975.
- [8] David B. Gerritsen, Dan Tasse, Jennifer K. Olsen, Tatiana A. Vlahovic, Rebecca Gulotta, William Odom, Jason Wiese, and John Zimmerman. 2016. Mailing Archived Emails as Postcards: Probing the Value of Virtual Collections. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). Association for Computing Machinery, New York, NY, USA, 1187–1199. DOI: <http://dx.doi.org/10.1145/2858036.2858541>
- [9] Jane Gruning. 2018. Displaying Invisible Objects: Why People Rarely Re-Read E-Books. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). Association for Computing Machinery, New York, NY, USA, 1–12. DOI: <http://dx.doi.org/10.1145/3173574.3173713>
- [10] Rebecca Gulotta, Alex Sciuto, Aisling Kelliher, and Jodi Forlizzi. 2015. Curatorial Agents: How Systems Shape Our Understanding of Personal and Familial Digital Information. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15). Association for Computing Machinery, New York, NY, USA, 3453–3462. DOI: <http://dx.doi.org/10.1145/2702123.2702297>
- [11] Aakar Gupta, Bo Rui Lin, Siyi Ji, Arjav Patel, and Daniel Vogel. 2020. Replicate and Reuse: Tangible Interaction Design for Digitally-Augmented Physical Media Objects. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20). Association for Computing Machinery, New York, NY, USA, 1–12. DOI: <http://dx.doi.org/10.1145/3313831.3376139>
- [12] Iben Have and Birgitte Stougaard Pedersen. 2012. Conceptualising the audiobook experience. *SoundEffects-An Interdisciplinary Journal of Sound and Sound Experience* 2, 2 (2012), 79–95.
- [13] Iben Have and Birgitte Stougaard Pedersen. 2020. The audiobook circuit in digital publishing: Voicing the silent revolution. *New Media & Society* 22, 3 (2020), 409–428.
- [14] Luc Hermans, Mendel Broekhuijsen, and Panos Markopoulos. 2017. Memora: A Design for Teenagers to Connect Virtual and Physical Possessions. In Proceedings of the European Conference on Cognitive Ergonomics 2017 (ECCE 2017). Association for Computing Machinery, New York, NY, USA, 121–128. DOI: <http://dx.doi.org/10.1145/3121283.3121312>
- [15] Annika Hinze, Dana McKay, Nicholas Vanderschantz, Claire Timpany, and Sally Jo Cunningham. 2012. Book Selection Behavior in the Physical Library: Implications for Ebook Collections. In Proceedings of the 12th ACM/IEEE-CS Joint Conference on Digital Libraries (JCDL '12). Association for Computing Machinery, New York, NY, USA, 305–314. DOI: <http://dx.doi.org/10.1145/2232817.2232874>
- [16] Eva Hornecker and Jacob Buur. 2006. Getting a Grip on Tangible Interaction: A Framework on Physical Space and Social Interaction. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '06). Association for Computing Machinery, New York, NY, USA, 437–446. DOI: <http://dx.doi.org/10.1145/1124772.1124838>
- [17] Steven Houben, Connie Golsteijn, Sarah Gallacher, Rose Johnson, Saskia Bakker, Nicolai Marquardt, Licia Capra, and Yvonne Rogers. 2016. Physikit: Data Engagement Through Physical Ambient Visualizations in the Home. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). Association for Computing Machinery, New York, NY, USA, 1608–1619. DOI: <http://dx.doi.org/10.1145/2858036.2858059>
- [18] Annika Hupfeld and Tom Rodden. 2014. Books as a Social Technology. In Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work amp; Social Computing (CSCW '14). Association for Computing Machinery, New York, NY, USA, 639–651. DOI: <http://dx.doi.org/10.1145/2531602.2531647>
- [19] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karnik, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and Challenges for Data Physicalization. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15). Association for Computing Machinery, New York, NY, USA, 3227–3236. DOI: <http://dx.doi.org/10.1145/2702123.2702180>
- [20] Mads Møller Jensen, Roman Rädle, Clemens N. Klokmose, and Susanne Bodker. 2018. Remediating a Design Tool: Implications of Digitizing Sticky Notes. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). Association for Computing Machinery, New York, NY, USA, 1–12. DOI: <http://dx.doi.org/10.1145/3173574.3173798>
- [21] Somi Ju, Kyung-Ryong Lee, Subin Kim, and Young-Woo Park. 2019. Bookly: An Interactive Everyday Artifact Showing the Time of Physically Accumulated Reading Activity. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19). Association for Computing Machinery, New York, NY, USA, 1–8. DOI: <http://dx.doi.org/10.1145/3290605.3300614>
- [22] Kyung Jin Kim, Sangsu Jang, Bomin Kim, Hyosun Kwon, and Young-Woo Park. 2019. MuRedder: Shredding Speaker for Ephemeral Musical Experience. In Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19). Association for Computing Machinery, New York, NY, USA, 127–134. DOI: <http://dx.doi.org/10.1145/3322276.3322362>
- [23] Sarah Kozloff. 1995. Audio books in a visual culture. *The Journal of American Culture* 18, 4 (1995), 83.

- [24] Daye Kwon and Woohun Lee. 2018. Artifact Mixtape: Curating Music in Personal Tangible Artifacts. In Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems (DIS '18 Companion). Association for Computing Machinery, New York, NY, USA, 265–270. DOI: <http://dx.doi.org/10.1145/3197391.3205447>
- [25] Andrew Manches, Claire O'Malley, and Steve Benford. 2009. Physical Manipulation: Evaluating the Potential for Tangible Designs. In Proceedings of the 3rd International Conference on Tangible and Embedded Interaction (TEI '09). Association for Computing Machinery, New York, NY, USA, 77–84. DOI: <http://dx.doi.org/10.1145/1517664.1517688>
- [26] Kazuhiro Matsushita, Daisuke Iwai, and Kosuke Sato. 2011. Interactive Bookshelf Surface for in Situ Book Searching and Storing Support. In Proceedings of the 2nd Augmented Human International Conference (AH'11). Association for Computing Machinery, New York, NY, USA, Article 2, 8 pages. DOI: <http://dx.doi.org/10.1145/1959826.1959828>
- [27] Donald McMillan, Barry Brown, Abigail Sellen, Siân Lindley, and Roy Martens. 2015. Pick up and Play: Understanding Tangibility for Cloud Media. In Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia (MUM '15). Association for Computing Machinery, New York, NY, USA, 1–13. DOI: <http://dx.doi.org/10.1145/2836041.2836042>
- [28] Barry D. Moore. 2020. Audiobook Statistics Reveals How Experts Use Audiobooks. (2020). <https://www.greatworklife.com/how-to-listen-to-audiobooks-statistics>
- [29] Tatsuo Nakajima, Vili Lehdonvirta, Eiji Tokunaga, and Hiroaki Kimura. 2008. Reflecting Human Behavior to Motivate Desirable Lifestyle. In Proceedings of the 7th ACM Conference on Designing Interactive Systems (DIS'08). Association for Computing Machinery, New York, NY, USA, 405–414. DOI: <http://dx.doi.org/10.1145/1394445.1394489>
- [30] Wendy Nie, Tugce Tasci, and R. Pidaparthi. 2013. Book and Audiobook Synchronization.
- [31] Musa Nushi and Mohamad Hosein Eqbali. 2017. Duolingo: A Mobile Application to Assist Second Language Learning. *Teaching English with Technology* 17, 1 (2017), 89–98.
- [32] Jonathan Nyström Müller and Casper Engström. 2019. Consumer adoption of audiobook streaming services. (2019).
- [33] William Odom, Richard Banks, David Kirk, Richard Harper, Siân Lindley, and Abigail Sellen. 2012a. Technology Heirlooms? Considerations for Passing down and Inheriting Digital Materials. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12). Association for Computing Machinery, New York, NY, USA, 337–346. DOI: <http://dx.doi.org/10.1145/2207676.2207723>
- [34] William Odom, Abi Sellen, Richard Harper, and Eno Thereska. 2012b. Lost in Translation: Understanding the Possession of Digital Things in the Cloud. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12). Association for Computing Machinery, New York, NY, USA, 781–790. DOI: <http://dx.doi.org/10.1145/2207676.2207789>
- [35] William Odom, John Zimmerman, and Jodi Forlizzi. 2014. Placelessness, Spacelessness, and Formlessness: Experiential Qualities of Virtual Possessions. In Proceedings of the 2014 Conference on Designing Interactive Systems (DIS '14). Association for Computing Machinery, New York, NY, USA, 985–994. DOI: <http://dx.doi.org/10.1145/2598510.2598577>
- [36] William Odom, John Zimmerman, Jodi Forlizzi, Ana López Higuera, Mauro Marchitto, José Cañas, Youn-kyung Lim, Tek-Jin Nam, Moon-Hwan Lee, Yeoreum Lee, Da-jung Kim, Yea-kyung Row, Jinmin Seok, Bokyung Sohn, and Heather Moore. 2013. Fragmentation and Transition: Understanding Perceptions of Virtual Possessions among Young Adults in Spain, South Korea and the United States. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13). Association for Computing Machinery, New York, NY, USA, 1833–1842. DOI: <http://dx.doi.org/10.1145/2470654.2466242>
- [37] Anna-Marie Ortloff, Lydia Günther, Maximiliane Windl, Thomas Schmidt, Martin Kocur, and Christian Wolff. 2019. SentiBooks: Enhancing Audiobooks via Affective Computing and Smart Light Bulbs. In Proceedings of Mensch Und Computer 2019 (MuC'19). Association for Computing Machinery, New York, NY, USA, 863–866. DOI: <http://dx.doi.org/10.1145/3340764.3345368>
- [38] Matthew K.X.J. Pan, Gordon Jih-Shiang Chang, Gokhan H. Hımmetoglu, Ajung Moon, Thomas W. Hazelton, Karon E. MacLean, and Elizabeth A. Croft. 2011. Galvanic Skin Response-Derived Bookmarking of an Audio Stream. In CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11). Association for Computing Machinery, New York, NY, USA, 1135–1140. DOI: <http://dx.doi.org/10.1145/1979742.1979716>
- [39] Daniela Petrelli and Steve Whittaker. 2010. Family memories in the home: contrasting physical and digital mementos. *Personal and Ubiquitous Computing* 14, 2 (2010), 153–169.
- [40] Mark Rouncefield and Peter Tolmie. 2011. Digital Words: Reading and the 21st Century Home. Springer London, London, 133–162. DOI: [http://dx.doi.org/10.1007/978-0-85729-476-0\\_8](http://dx.doi.org/10.1007/978-0-85729-476-0_8)
- [41] Rishi Shukla and Rebecca Stewart. 2017. Metronome Music Time Capsule: Re-materialising Music Consumption and Exchange. In Proceedings of the 12th International Audio Mostly Conference on Augmented and Participatory Sound and Music Experiences (ÄM'17). Association for Computing Machinery, New York, NY, USA, Article 6, 4 pages. DOI: <http://dx.doi.org/10.1145/3123514.3123548>
- [42] Alice Thudt, Uta Hinrichs, Samuel Huron, and Sheelagh Carpendale. 2018. Self-Reflection and Personal Physicalization Construction. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). Association for Computing Machinery, New York, NY, USA, 1–13. DOI: <http://dx.doi.org/10.1145/3173574.3173728>
- [43] Lukas Van Campenhout, Joep Frens, Caroline Hummels, Achiel Standaert, and Herbert Peremans. 2019. The enriching limitations of the physical world. *Personal and Ubiquitous Computing* 23, 1 (2019), 81–98.
- [44] LDE Van Campenhout, JW Frens, CJ Overbeeke, Achiel Standaert, and Herbert Peremans. 2013. Physical interaction in a dematerialized world. *International Journal of Design* 7, 1 (2013), 1–18.
- [45] John Zimmerman and Jodi Forlizzi. 2014. Research through design in HCI. In *Ways of Knowing in HCI*. Springer, 167–189.