Hicclip: Sonification of Augmented Eating Sounds to Intervene Snacking Behaviors

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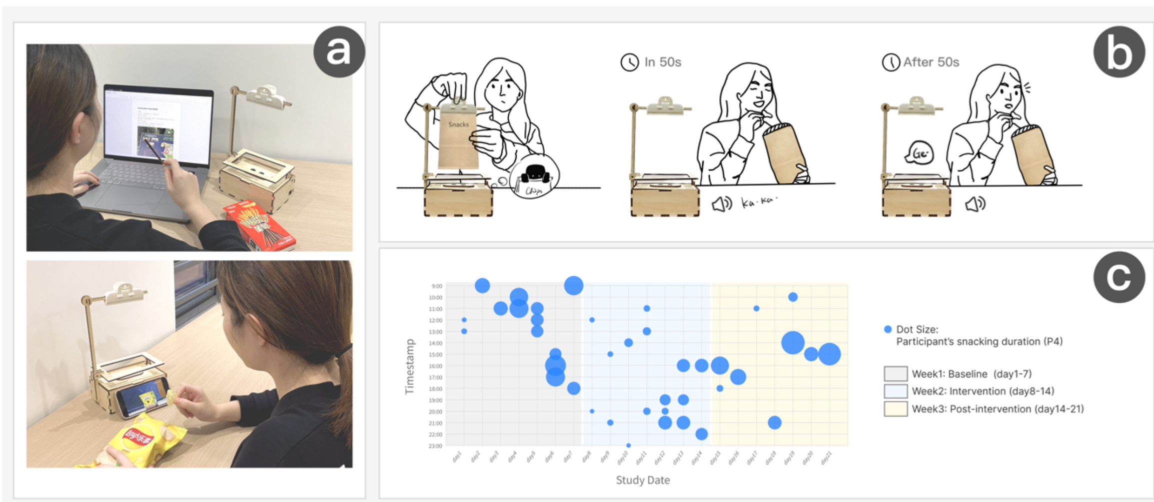

Figure 1: The image shows a) the use scenarios of Hicclip during the screen times; b) the interactive soundscape of Hicclip using augmented chewing and burping sounds; c) an example of the Hicclip system collected snacking behavioral data over the field study.

ABSTRACT

In this paper, we present a field study on using sonification of augmented eating sounds to intervene snacking behaviors in daily routines. The sonic feedback achieved through a snack storing device named Hicclip for verifying snacking behaviors and producing augmented eating sounds. The study was conducted with nine participants who were commonly addicted to snacking. The effectiveness of the sonification was examined by comparing snack-related data and questionnaire over the three study weeks: a baseline week, a Hicclip intervention week, and a post-intervention week. We also analyzed interview results to understand user experiences and opportunities for future research. Quantitative results showed that the snacking pattern has been improved due to reduced eating duration and snack consumptions. Qualitative results suggested that Hicclip may benefit self-regulation, afford easy adoption, and support data acquisition. We discuss design implications for embodiment of augmented eating sounds for healthy snacking.

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction (HCI); Interaction design.**;

KEYWORDS

Healthy eating, snacking behavior, sonification, sonic interaction

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1 INTRODUCTION

Nowadays, people tend to consume more snacks with high energy, fats, sugars, and sodium. Alongside energy and nutrition supplement, snacks also serve non-nutritive functions, such as fostering social interaction, offering emotional support, and assisting in stress management [45]. Although snack is ubiquitous in the modern food environment and considered as an important part of everyday dietary patterns, it has been associated with some health issues, such as weight gain [32] and emotional eating [37], the excessive consumption of calorie-rich and less healthy snacks was identified as an important contributing factor to health crises [5]. Research has found various motivations for excessive snacking, including hunger, social/food culture, distracted eating, boredom, indulgence, and so on [14, 15].

In the human-computer interaction (HCI) community, there have been a few studies investigating scenarios for before or after snack intakes, such as intervening shopping [19, 39, 43] or encouraging reflection on past snack consumptions [44]. Additionally, one study by Hsu et al. [17] has developed a mobile app to guide users to eat low-calorie snacks by increasing health awareness in real-time. However, real-life snacking behaviors often occur unconsciously as a secondary activity [37]. For example, when snacking during screen time such as for entertainment, work, or social interaction purposes, the user could be unaware of what they are eating, how often they are chewing, and how satiated they feel [14]. In this case, typical persuasive technologies, such as mobile apps and desktop-based reminders, would become burdensome and could not effectively change users' attitudes towards healthier behaviors in daily routines [42].

To date, the growing advance in ubiquitous eating monitoring [29] and ambient displays [10] might bring opportunities for creating embodied experiences to seamlessly intervene unconscious snacking, without causing cognitive and behavioral burdens to users [56]. In order to boost awareness and action on healthy eating without cognitive burden through sensory interactions, one possible human-food interaction (HFI) that has been increasingly investigated is creating visual illusions to enhance satiety or reduce food intake [16, 46], which normally requires food modifications and high-fidelity technology implementations. On the flip side, we observed that sonic feedback might be easily leveraged as low-cost, embodied interventions to correct unconscious actions for improved snacking behaviors. In fact, the effectiveness of sonification have been well-studied in various health contexts [10]. For example, Newbold et al. [36] helped people relieve pain from chronic diseases by guiding moderate stretching exercises with interactive music. Through augmenting the sound of footsteps using wearable devices, Tajadura-Jiménez et al. [47] created an interactive system to unobtrusively correct users' walking postures. Moreover, Ma et al. [30] integrated a gamified soundscape into collective physical play to improve children's intrinsic motivation to participate in physical education. Similarly, we believe that sonification could potentially lead embodied cognition to increase users' health awareness during unconscious snacking in daily life.

In HFI, there has been some perceptual research on understanding the relationships between food and sound. For instance, several studies have proved that individuals' eating speed could be associated with the rhythm of background music [31, 34]. In addition, an experiment by Bruno Mesz et al. [33] revealed the potential that alcohol consumption could be influenced by the effect of interactive music on wine taste. For snack-related sound research, Koizumi et al. [26] found that the perceived flavor of chips could be changed due to modified chewing sounds. Kleinberger et al. [24] investigated different altering modes of chewing sounds on affecting appetite and revealed that amplifying eating sounds could raise awareness of food and potentially help reduce unconscious eating. While these findings were primarily based on controlled laboratory settings, it remains susceptible whether sounds could be leveraged to encourage healthy eating in the real-life settings. Following a theory of magnitude [50] , further, in this paper we were interested in understanding how the exaggerated eating sounds could be utilized and embodied for intervening mindless snacking and reducing snack intakes based on empirical research.

In this paper, we present a three-week field study with nine participants using a research probe called Hicclip [28], a smart sealing rack for snacks that can be placed on the table to offer real-time sonification of amplified eating sounds in response to the user's snacking behaviors (see Fig. 1). The study was designed in three stages: a baseline week, a sonification-based intervention week, and a post-intervention week. Hicclip was deployed throughout the entire study but only provided the sonic feedback during the intervention week. A mixed method was applied to collect sensor data from Hicclip and questionnaire responses to quantitatively examine the effectiveness of incorporated sonification in reducing over-snacking as well as eating motives and self-regulation. Moreover, we conducted in-depth interviews with participants to serve the interpretation of quantitative data and derive implications for future research. Our paper makes following two contributions:

First, our study provides empirical evidence that augmented eating sounds can improve snacking behavior by enhancing participants' self-awareness, thus facilitating the regulation of unconscious over-snacking.

Second, we offer design implications for leveraging embodied sonification with tangible products as simple, ubiquitous, and enjoyable HFI interfaces to intervene snacking behaviors in real-life contexts.

2 RELATED WORK

2.1 HFI for Promoting Healthy Eating

Increasingly, ubiquitous computing and wearable HFI have been investigated to support the formation of healthy eating habits. For example, prior research has leveraged the audio sensor on smartwatch devices [20] and smart glasses [4] to recognize chewing and swallowing. However, wearable technologies require users to wear additional equipment while eating, which could incur additional cognitive efforts and adversely impact the enjoyment and comfort while eating [40]. By contrast, combining HFI with eating-related objects provides some opportunities for unobtrusive monitoring and seamless interaction in health behavior change [13]. For example, *Mindless Plate* is a smart plate that can change its colors according to the foods' color to create an illusion of there being more food [1]. *Eat2pic* is consists of a pair of sensor-equipped chopsticks to automatically recognize the food being eaten and a digital canvas that maps nutrients into different colors for real-time painting for increased self-awareness on balanced diets [35]. *SWAN* is a smart spoon that can track the frequency of spoon usage and help users adjust eating pace through vibration and wobbling motions to reduce distractions during meals [23].

While there is considerable interest in leveraging ubiquitous technologies to understand dietary patterns or improve meal-related eating behaviors, the specific focus on addressing snack indulgence appears to be less developed [56]. The lack of HFI approaches fails to help people reflect snacking habits and hinder effective interventions. Moreover, compared to main meals, snacking occasions often occur in casual and irregular contexts and could be influenced by various environmental and subjective factors. Therefore, targeted HFI strategies are needed to effectively monitor and intervene in snacking behaviors [17]. Next, we explore relevant research that specifically addresses unhealthy snacking behaviors.

2.2 HFI for Intervening Snacking Behaviors

Nowadays, snacking has been an integral part of individuals' dietary patterns [2]. In HFI, there have been two types of research on promoting healthy snacking, focusing on *snack choices* and *eating behaviors*, respectively. Regarding supporting users to choose healthier snacks, various studies explored using persuasive strategies to influence the decision-making process. For example, *Monster Appetite* [19] is a nutrition game aimed to deepen users' understanding of the dangers of unhealthy snacks through the mapping of users' calorie choices and the appearance of their monster avatar. In addition, Reinhardt et al. [43] investigated how the heuristic messages on the vending machine can motivate users to select healthy snacks under low self-control.

Regarding intervening snacking behaviors, research have employed digital elements of mobile applications to help users reduce snacking behaviors. For instance, a gamified app called *Snack Buddy* [44] facilitates family members to collectively record and mutually monitor each other's snacking intakes, support them to exchange health information. Similarly, using the external persuasive messages to encourage healthy behavior, Kaptein et al. [21] used tailored text messages to reduce snacking. Besides raising health awareness at the stage before or after snack intake, HFI researchers investigated opportunities of interactive systems to intervene snacking behaviors in real time. A study by Hsu et al.[17] leveraged app-based visual imagination prompts to reduce users' dietary cravings just before getting snacks and amplify users' sense of achievement gained by active behavior change. However, this type of systems still requires users to pay attention to health-awareness information, which might not be applicable to unconscious, emotional snacking in daily routines, especially when the user is paying attention to entertainment, work, or social chat [37].

Moreover, increasingly, HCI researchers developed interactive technologies to create multisensory experiences to unobtrusively support health behavior change. Particularly, sound-based interactions have presented advantages in providing lightweight yet embodied intervention to correct unconscious unhealthy behaviors [24]. Next, we present some existing HFI studies on sonification for health promotion.

2.3 Sonification in HFI

In the field of Human-Food Interaction (HFI), there are two main types of sound-based interaction research: enhancing the dining experience through sound and exploring the impact of sound on food perception [12]. Firstly, the interactive sounds have been combined with food or tableware to offer playful sonic feedback while eating. For instance, *WeScream!* [51] is a pair of two ice cream cones equipped with musical sound modules. Users who eat together can trigger different gamified sounds, enhancing their technology-augmented social eating experiences. *FoBo* [22] is a social robot that mimics the chewing and burping sounds of human beings to support companionship for individuals while eating alone. There has also been increasing investigation into the role of sounds in affecting diet-related perception to create cross-sensory experiences [7]. A portion of the study focused on sound stimuli within the environment, for instance, through experimenting with the *Sonic Mug* [31], a cup that can trigger music by drinking action, the study found that the users' soundtracks liking could influence how they taste the sweetness of the coffee drink. Carvalho et al. [8] found that music could also matter how people drink alcohol. Similarly, Mesz et al. [33] developed an augmented glass, which has shown the potential of using music with different pitches to influence drinking experiences. Besides, there are also research investigating the manipulation of closed-loop auditory to influence the perception. For snacking, *Chewing Jockey* [26] alters the chewing sound to influence the perception of chip crunchiness. Furthermore, Kleinberger et al. [24] conducted a lab experiment on sonic feedback of chewing sounds and revealed its correlation with the flavor of snacks.

While HFI research on sonification has extensively explored from the experience perspective, their applications in modifying unhealthy eating behaviors were limited. Existing behavior change research mainly considered sonic feedback as an efficient alert giving by a health audio assistant for specific user groups like children and parents [27], or a straightforward guidance to correct eating speed [9], encouraging mindful eating [55], etc. Few studies have considered adopting embodied sonic experiences as a means for aiding unhealthy snacking behaviors. To mind this gap, we hoped to investigate sound augmentations to experientially affect mindless snacking behaviors in users' daily routines. In line with aforementioned insights, this paper set out a design prototype and a field study, aiming to explore the augmented eating sounds as a means of real-time interaction to facilitate healthy snacking experiences.

3 HICCLIP

3.1 Design Process

The design process of Hicclip aimed at enabling real-world monitoring of users' snacking behaviors and affording sonic feedback for daily use. Initially, group discussions among authors noted that snacks are often stored on desks, such as during work hours and leisure times like watching videos. This observation led us to develop a desktop device that serves as both a snack storage and

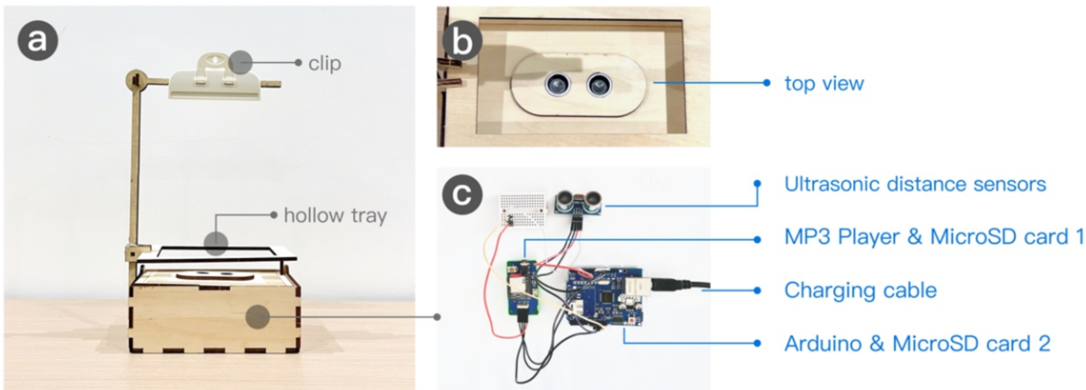

Figure 2: Technical Implementation of Hicclip.

monitoring unit. By tracking the removal and return of snacks, this device offers a rough yet effective method to observe snacking habits. Although it does not capture the exact amounts of consumption, it avoids the privacy issues tied to more invasive technologies like cameras and listening devices, thereby smoothing its integration into everyday environments.

In terms of the sonification, we considered that Hicclip should produce eating-related sounds that respond to and amplify the user's snacking actions. We focused on the sound of chewing, as previous studies have demonstrated the impact of closed loop chewing sounds on satiety and food perception [24]. We were curious about how people perceive amplified external chewing sounds. In addition, inspired by designs that incorporate anthropomorphic and emotional elements for health behavior change [23], we incorporated features that imbue Hicclip with a personality of its owner to improve user engagement. For instance, Hicclip emits chewing sounds when a snack is taken away by users and a humorous burping sound if the snack is not returned properly. Eventually, a crunching sound of a crispy snack[1] and an exaggerated, monster-like burping sound[2] were selected to represent the act of snacking while being fantastic, engaging, and non-repulsive.

3.2 Design Implementation

The prototype of Hicclip was implemented in three parts: a hanging bracket with a snack closure clip, a hollow snack tray and a base (Fig. 2(a)). The base is fitted with electronic components, mainly containing sensors that monitor the status of the snack storage and a sound player that controls the program via the Arduino. In addition, we installed an SD card expansion on the Arduino to record user behavior data during the experiment. (Fig. 2(b) and (c)). Particularly, the ultrasonic range sensor was applied, continuously detecting the distance between the object above and the upper surface of the base, and determining whether the user has taken, or put back, the snack by the change in distance. The height setting passed our simple self-test, where we chose 10 high-calorie snack package sizes and weights commonly found in campus shops to ensure that most of the snacks could be hung or placed on the Hicclip.

In addition, the SD card in the mp3 module stored the previously mentioned chewing and burping sounds. The volume of the chewing sound was set to 45db and the length of the whole audio was 9s, and the volume of the burping sound was set to 60db and the length was 1s. This volume was picked based on our simple self-tests under the condition that the Hicclip was within 5m from the user, which somewhat ensured that the user, while wearing non-in-ear headphones to play videos or engage in other recreational activities, would still be able to hear the chewing sound and can clearly notice the sound of burping. The detail of the sonification mechanism of Hicclip has been summarized in Table 1.

During Hicclip's operation, these two sounds are looped according to the user's behavioral conditions and the time set by the program. The user experience flow of Hicclip is presented in Fig. 3

4 USER STUDY

We employed Hicclip as a technology probe [18] to explore the potential effectiveness and user experience of sonic feedback as a means of snacking intervention, as well as to understand how it could be designed and iterated to meet user expectations in real-life settings. The goal of the study is to know about:

RQ1: Whether and how does the feedback of augmented eating sounds from Hicclip support users to improve self-regulation of excessive snacking consumptions?

RQ2: How do users experience Hicclip with sonification as a day-to-day intervention for healthy snacking?

4.1 Participants

This study received the research ethics approval from the committee at Beijing Institute of Technology. During recruiting, we took a snowball sampling approach, and 13 participants were initially recruited for this experiment but four withdrew during the study.

[1]https://www.aigei.com/s?q=%E6%89%93%E5%97%9D&type=sound
[2]https://www.aigei.com/s?q=%E5%92%80%E5%9A%BC&type=sound

Table 1: The sonification mechanism of Hicclip

State of users	Duration (seconds)	Sounds
Did not start eating	0	silent
Take the snack	0	silent
Eating	50s	Chewing
Eating	After 50s	Burping
Return the snack back	Any time	silent

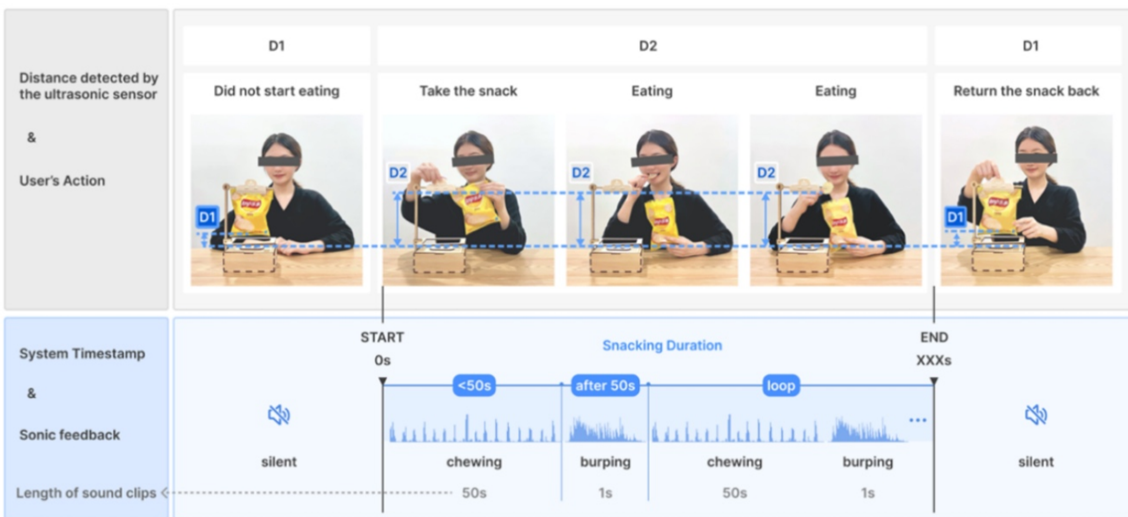

Figure 3: The user experience flow of Hicclip.

Table 2: Participants

Label	Gender	Age	BMI	Average Snacking Frequency (per day)
P1	Male	22	20.2	1-2 times
P2	Male	23	25.5	3-4 times
P3	Male	24	21.6	1-2 times
P4	Male	20	28.7	Above 4 times
P5	Female	20	23.7	1-2 times
P6	Male	23	19.6	3-4 times
P7	Female	22	23.9	Above 4 times
P8	Female	22	19.1	3-4 times
P9	Female	22	21.0	3-4 times

Our participants were aged between 20 and 24 (M = 22.11, SD = 1.17), and their BMI ranged from 19.1 to 28.7. They were all undergraduate or postgraduate students from four universities located in different cities in China, with varied study backgrounds, including design and arts, psychology, aerospace, journalism, etc. All participants had a habit of consuming high-calorie snacks, especially during screen time with their computers or mobile phones. They generally engaged in screen use for more than six hours per day, due to study, entertainment, and social purposes. We labeled the nine participants as P1, P2, . . ., and P9. The detail background information of the participants has been summarized in Table 2.

4.2 Procedure and Data Collection

The study was conducted during the Spring season in China. Fig. 4 shows the complete experimental flow.

The study consisted of three phases: baseline, intervention, and post-intervention, each spanning a week's duration. Sound feedback was only activated during the intervention week, while it was turned off in the baseline and post-intervention weeks. The study

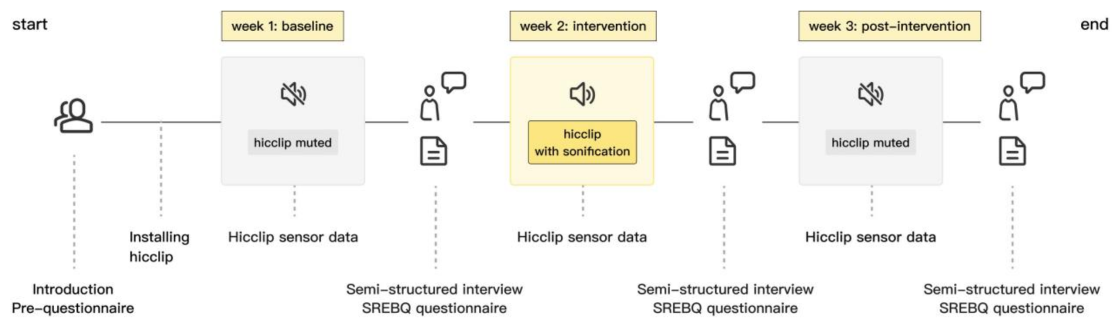

Figure 4: The study procedure.

was initiated by explaining the study procedure without discussing the research questions, to avoid bias and ensure the objectivity of participants' behaviors. Afterwards, each participant received a set of Hicclip prototype as well as instructions for assembly and software installation. At the beginning of the intervention week, we introduced the mechanism and features of sound feedback of Hicclip.

Throughout the three-week study period, participants utilized Hicclip to keep their packed snacks for daily usage. The SD card recorded the times when snacks were taken out and put back to generate visualizations of snacking frequency and duration. Fig. 1 (c) shows a sample of the visualization of system data recorded in study weeks. At the end of each study week, participants completed the Self-Regulation of Eating Behavior Questionnaire (SREBQ) [25] to track their self-awareness in regulating snacking behaviors under each condition. Following this, a semi-structured interview was conducted. First, we presented the visualization of Hicclip usage data and asked participants to interpret the data with questions like *"Could you look at your snack consumption data and photo logs and explain what eating behaviors were related to these data?"* Second, we asked participants to elaborate on their relevant experiences in the past week by asking questions such as *"Could you please share some stories about your experiences related to snacking behaviors last week?"* Third, we asked participants to assess the effects of Hicclip in intervening unconscious snacking with questions such as *"How did Hicclip influence your snacking behaviors in the past week?"* We also asked the participants to explain some interesting statements that emerged during the interview. All interview sessions were audio-recorded, reviewed, and summarized into transcripts for the thematic analysis [6].

4.3 Data analysis

We utilized mixed methods with quantitative and qualitative data to understand the effect and user experience of Hicclip. For quantitative data, we employed descriptive data analysis to compare differences among the three study weeks. Initially, we used the timestamp stored in the SD card within Hicclip to calculate the snacking frequency and duration under three conditions. This enabled us to obtain objective and quantitative insights into participants' snacking patterns and how these patterns varied across different conditions. Then, we calculated the mean of all items within the SREBQ to assess users' self-awareness regarding the regulation of snacking behaviors, thus revealing the perceived effectiveness of Hicclip. Regarding qualitative data, all interview transcripts were imported into Nvivo software for thematic analysis using a bottom-up approach. One author conducted the initial round of open coding. Subsequently, two authors conducted the selective coding process to extract insights into the interpretation of quantitative data and to identify the opportunities and challenges associated with the long-term utilization of Hicclip.

5 RESULTS

In this section, we present a mixture of quantitative and qualitative data to address our research questions and additional findings as opportunities to improve the current design and study.

5.1 The Reduction of Snacking Behaviors due to Hicclip

5.1.1 Changes of snacking duration during the study. During the study, we used Hicclip to collect the timestamp data of their snacking moments, by which we calculated their eating frequency and duration. As shown in Fig. 5(a), on average, our participants spent 6.41 minutes per day (SE = 1.55) on snacking during the intervention week, which is remarkably lower than 15.66 (SE = 3.61) minutes for the baseline and 11.73 (SE = 1.89) minutes for the post-intervention. According to Fig. 5(b)-(j), we learned that all participants simultaneously reduced their snack durations because of using Hicclip with the augmented eating sounds.

From study interviews, we learned several factors that might lead to reduced snack durations for our participants. First, some participants considered the augmented burping sound from Hicclip as an effective reminder to help them stop eating snacks. For example, P6 commented: *"It feels like the sound of burping is mainly used for suggesting that I was already full, I should eat less",* Similarly, P8 said, *"For me, this mode helps me to control quite a lot, [...] It's kind of funny that I was still eating when the machine was burping. It*

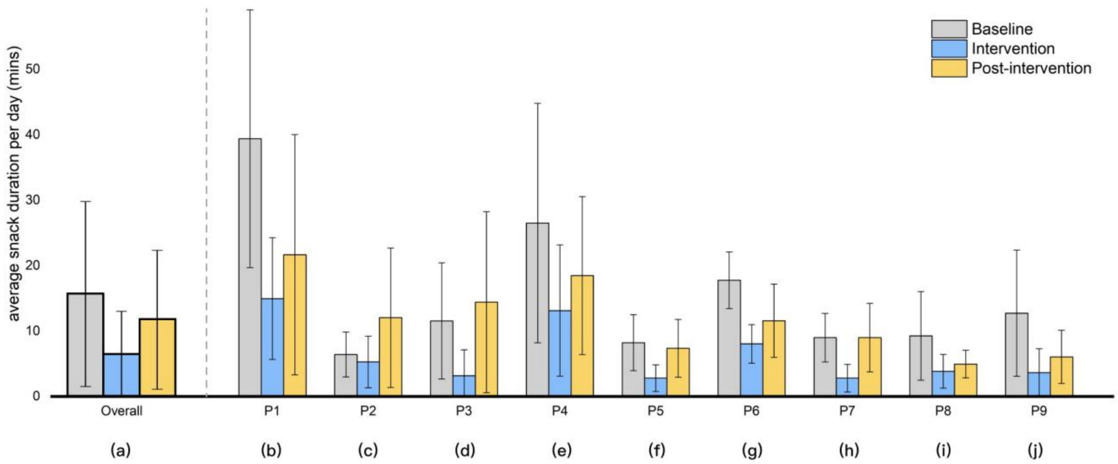

Figure 5: Mean and SD of participants' snacking durations throughout the entire study.

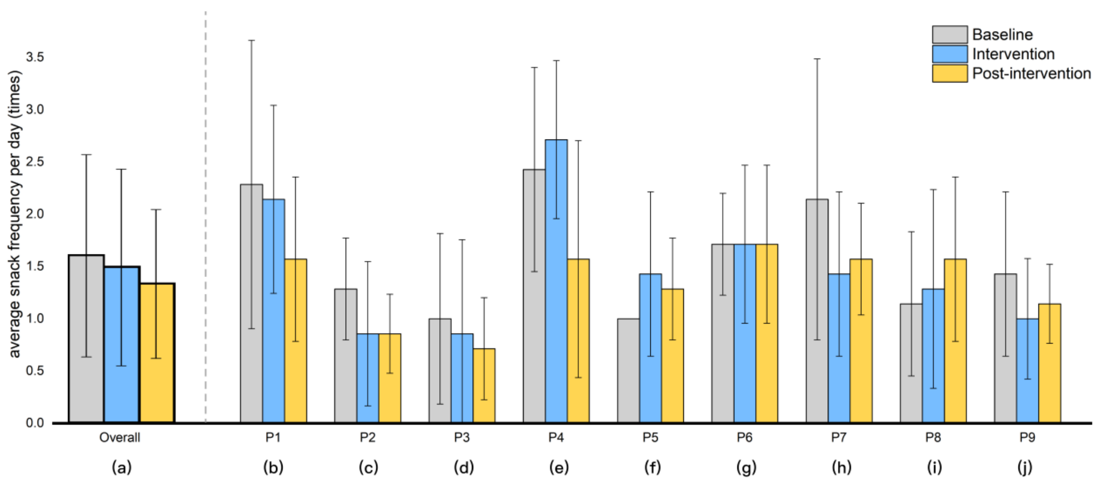

Figure 6: Mean and SD of participants' eating frequency throughout the entire study.

influenced my snacking self-control by the sound." Second, several participants felt that their snacking moments accompanied by the chewing soundscape made them become aware of their snacking behaviors. As P7 stated, *"I used to mindlessly eat all the time and quickly finish a bag of snacks. Now the sounds emphasized the action of eating, which made me aware of my intake. Then I could consciously put the snack down."* P3 also mentioned, *"as soon as I picked up the snack, it started to make a sound, which obviously reminded me to reflect on whether I need to stop eating in some condition."* Third, while a few participants had negative attitudes towards sonification, they still found such unpleasant sounds reduced their snacking time: e.g., *"It was a cute sound at first, but I felt annoyed when I regarded it as the noise later this week. However, it still worked because I ate less to get rid of its sounds"* (P9), and *"The chewing sound makes me uncomfortable, it is an electronic noise to me, I finish snacking as quickly as possible or simply chose not to eat to avoid it."* (P4).

5.1.2 Changes of eating frequency during the study. Fig. 6(a) shows that the daily snacking frequency of our participants had decreased from 1.60 times per day (SE = 0.19) to 1.49 times per day (SE = 0.21) between the baseline and the intervention weeks, which increased to 1.33 (SE = 0.12) for the post-intervention period. Fig. 6 (b)-(j) further indicated that more than half of our participants (5/9) reduced their eating frequency due to Hicclip. P8 continually increased snacking frequency from the baseline to the intervention and the post-intervention weeks, whereas the average daily snacking frequencies of P6 were identical among the three study weeks. On the contrary, P4 and P5 snacked slightly more times in the intervention week than in the baseline and the post-intervention.

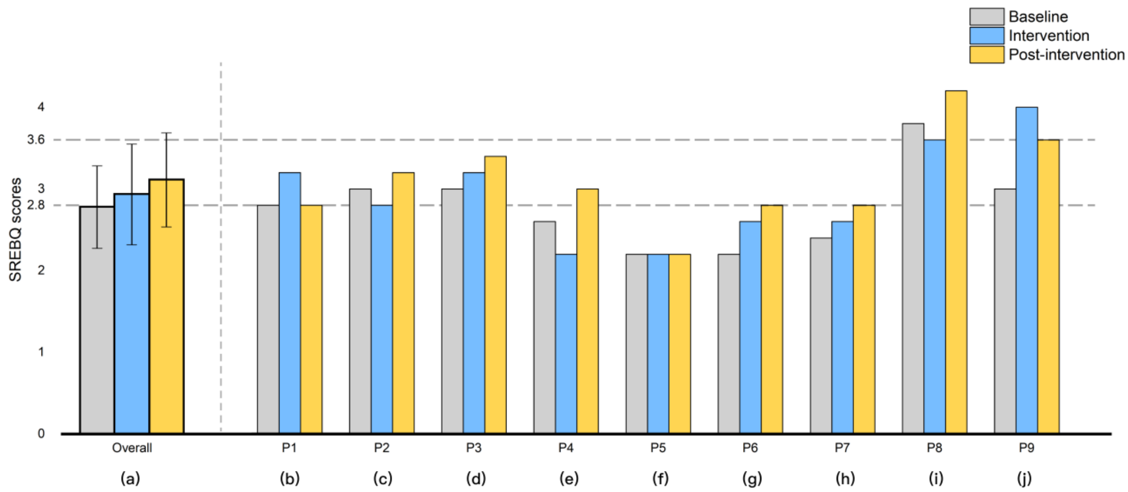

Figure 7: Mean and SD of participants' SREBQ scores after the baseline, the intervention, and the post-intervention.

We learned from the interviews that sonification from Hicclip hindered most of our participants from initiating snacking behaviors. For instance, many participants minimized their snacking frequencies to avoid activating the sounds from Hicclip. As described earlier, P9 felt the sounds were annoying after a few days and wanted to avoid them. Therefore, P9 only snacked once per day during the Hicclip intervention week. Furthermore, several participants used our prototype in the shared space and found the sound-based interactions might be socially undesirable. Taking P2 's words as an example: *"I felt the sounds [from the Hicclip speaker] can be easily noticed by people around me, and I didn't want my snacking time to be known by everyone."* And P6 also said: *"I used to eat quite a lot at night, but this week I've been eating less. I was ready to take snacks but stopped when I thought of the sounds. Because I'm always worried about it affecting the rest of the family sleeping."* When checking with P4, P5, and P8 for their reasons for the raised eating frequencies, we learned that they tried to snack more times to compensate for the lowered snacking duration. As P4 said, *"Because I knew I need to stop whenever the burping sound is out, I insisted to grab the pack more times to enjoy more snacks without triggering the 'warning burping'."*

5.1.3 Changes of self-regulatory capacity of eating during the study. By comparing the SREBQ data over the three weeks, we were able to understand whether the intervention impacted participants' self-control on healthy eating. According to Fig. 7, our participants' self-regulation of eating behavior has increased from 2.78 (SE = 0.17) in the baseline week to 2.93 (SE = 0.20) in the intervention week and 3.11 (SE = 0.19) in the post-intervention week. Specifically, six out of nine participants (P2, P3, P4, P6, P7, and P8) gave the highest SREBQ scores after the post-intervention week, whereas P1 and P9 scored their SREBQ highest after the intervention week. P5 did not change her SREBQ scores too much during the study.

We used some system data of Hicclip and participants' feedback in interviews to help us interpret these changes in questionnaire results. Noteworthy, participants who rated their SREBQ scores highest in the post-intervention week expressed that they developed new snacking habits after the intervention. For instance, P2 said, *"I felt as if the chewing and burping still ringing in my head after the withdrawal of intervention."* P8 thought the experience of sound-based interactions with Hicclip created a new connection between the sounds and snacking behaviors. She said: *"For my last experiment week, I did literally put the snack bag back when any sounds came to me."* In addition, some participants said that although the Hicclip stopped making sounds in the third week, the sight of the Hicclip and the action of opening the clip for snacks continued prompting them to think that "I should control snacking." The examples were as follows. P7 thought: *"The action of taking snacks off made me more conscious of the intake, then I avoided the continuous eating."* Similarly, P4 said: *"Hicclip was placed there as a reminder of the activity I was doing (controlling snacking), so I would subconsciously tell myself to cut down snacks intake."* Whereas P1 and P9 had their SREBQ scores peak in the intervention week, their explanations were: *"In the second week, I began to reject the sounds and my appetite may have decreased along with it. So, after the sounds withdrew, I seemed to retaliate by ingesting more (P9)." "It feels like Hicclip had less and less effect on me while I was more and more familiar with it. I started to eat a little out of control again in the third week (P1)."*

5.2 User Experiences of Hicclip with Sonification

Based on our interviews, we received qualitative feedback on the user experience of Hicclip in daily routines, which can be classified into two themes, namely: the benefits of Hicclip for promoting healthy snacking, and the challenges related to adopting Hicclip for everyday use.

5.2.1 Theme 1: The augmented eating sounds facilitated multisensory experiences for regulating snacking behaviors. Participants reported their interpretations the sounds feedback. For the value of chewing sounds, they perceived it helped them be prudent to unconscious snacking and be aware of snack consumptions. For example, P3 said, *"The constant sound kept reminding me to pay attention to my snacking movements, basically eliminating the reckless snacking while daze time, which existed to me before."* Furthermore, our participants had varied sentiments about the sound. Some participants felt that the sound was metaphorically reflecting their own chewing behavior, take P9 as an example, she said: *"That sound is similar to the sound of me chewing on a crunchy snack, and the constant sound created the illusion that I've eaten a lot."* In addition, at the very beginning of the experiment, some participants felt that the sound interaction was innovative and amusing, e.g., P5 said, *"The chewing sound did catch my attention, just like a character from a cartoon who supervise me to eat less snacks."*

The burping sound was mostly perceived as a cue or a warning for over-snacking. For some participants, the burping sound played a major role in interfering eating behaviors. (P1,P2,P4,P7,P9) They described the following experiences: *"The loud burping always alarmed me, then I suddenly realized that I should stop snacking"* (P7) Moreover, many participants believed that the sound of burping could influence their appetite, P8 and P6 said similar words: *"The burping sound made me feel full".* In addition, some participants think the augmented burping sound was a humorous and ironic way to intervene snacking, P8 mentioned, *"The burping sound is quite funny as if even this machine was stuffed up when I had too much snack. It would be sarcastic if I didn't stop eating."*

5.2.2 Theme 2: The sonic feedback supported snack interventions by design affordance and enjoyment. The Hicclip prototype allowed participants to easily understand feedback mechanisms through simple actions of picking up or returning snack packs. During the study, most participants mentioned that they got used to Hicclip very quickly and agreed that the device could be integrated into their daily routines. For example, P6 said, "For the first two days, Hicclip was an intriguing new thing that I couldn't help to interact with it." and P3 also said, "Overall I adopt Hicclip quickly and naturally."

Furthermore, the representative feedback mechanism led some participants to associate chewing and burping sounds with snack intake in their minds (P3, P4, P6, P8). As P8 said, *"In the later stages of the experiment, whenever I wanted to control snacking, the muted Hicclip can still remind me of* the *sounds, the burping sound in my head can help me control my intake time."* Additionally, the rhythm of the two sounds gave participants a sense of time while snacking. p3 mentioned, *"I typically snack while watching TV, it is a scenario easy to lose the sense of time. However, the prominent burps easily caught my attention, and after using Hicclip several times, I have gain awareness of moderate snacking time."*

When comparing Hicclip with the typical diet management app, we also found the sonic feedback mechanism capsuled into a tangible device made it more enjoyable for the user to record data for health tracking, e.g., "*After interacting with the device with the sounds, I felt playfulness of Hicclip and I was convinced with the data security.* (P3)". In addition, some participants mentioned that after understanding the function of Hicclip, they built the connection between sonification and self-reflection: "*The sound made by the Hicclip boosted my awareness of the snacking frequency, I was surprised to see the relationship between my snacking patterns and study stress. [...] Later on, the sounds reminded me to reflect on emotional eating* (P4)".

5.2.3 Theme 3: Varied personal experiences with unified sonification mechanism. Despite Hicclip with its sonification being found to be beneficial for health promotion by most participants in our study, it still faced some challenges for everyday use in the long term. Based on participants' suggestions, we have summarized existing problems that hindered the adoption of the sonification in Hicclip as following.

After the midpoint of the sound intervention experiment, some participants suggested that the sound was annoying at times, for example, P7 gave feedback: *"When I was tempting to enjoy a snack and have a good time, I thought* about *disconnecting the Hicclip switch to shut it up for a while."* Also, P4 was bothered due to the chewing sound was constant and unchanging, he said, *"it's uncomfortable with the constant electronic sound after a few days of using it."* Hence, some participants anticipated the parameters of sonification (e.g., the density of sounds, the levels of volume) could be customized according to their preferences and different contexts. As P5 said: *"Hicclip always gives chewing sound as the feedback, but it doesn't work for me all the time, especially under conditions where I'm conscious and proactive about controlling my snacking intake. Maybe it's a good idea to provide a different soundscape (encouraging) when my intake meets my healthy eating goal".* Furthermore, although many participants rated Hicclip as an effective tool for intervening snacking, they still experienced the provided sonic feedback as boredom for longer time use, as expected to be able to update the sounds at ease. As P8 mentioned: *"For long term use, I'd like it to be more personalized, support for volume adjustment and sound customization. For example, having my friends' voice record, as a funny sound reminder".*

5.2.4 Theme 4: The tangible interaction and sound source were inadaptable for different scenarios in the daily routines. As for this exploratory field study, Hicclip implemented with very simple sensors without being capable of recording more diversity of snacking related data, such as the quantity of foods. This has resulted in a lack of feedback on calorie intakes, which is crucial for nutrients self-management. For example, P5 raised her concern "I hope to control my calorie intake and I would like Hicclip to give me a timely sonic reply on my calorie intake." P6 suggested for the improvements, "Perhaps, Hicclip could be equipped with a camera or a weight sensor to record calories directly." Furthermore, when being asked to imagine the future prototype with enriched data, some participants also provided some suggestions on improving the sonic feedback of Hicclip. As P3 said, "Hicclip could be equipped with a screen displaying the amount of snack consumed as the volume of the sounds, then the user needs to be cautious about their snacking intake to keep the sounds at a pleasant level." This also implies that with more data feed into the system, the sound-based interaction could be optimized further to offer more relevant information to the user while snacking.

In this study, we integrated a speaker into the Hicclip prototype to allow snacking behavior feedback. According to our interviews, we found that this single way of sound provision was not that considerate for the dynamic of daily routines. For example, several participants experienced awkward moments while using Hicclip in shared spaces like dorms (P2, P3), labs (P1), shared flats (P8), or the family home (P6). Although P2 said, "*This audible sound makes those around me know I'm eating, it becomes a factor in me refraining from snacking.*" Such adverse experiences demotivated them to keep using the system. Moreover, a few participants also mentioned that, the location and volume settings of Hicclip might also influence how users perceive the intervention. For example, P2 stated, "*I'm usually watching a video with headphones on when I eat, which causes me to not be able to hear the external chewing sound.*" Similarly, P1 also raised the problem of missing data, "*Sometimes I eat a lot of snacks when I'm studying in the lab, but Hicclip was placed in my room most of the time, so it cannot support to stop my snacking behavior or record data.*" He explained the reason, "*It is inconvenient to bring Hicclip anywhere with me, and I worried about the sound disturbing other people.*"

6 DISCUSSION

The paper focuses on the design and experiment of Hicclip: an anthropomorphic and interactive snack holder that automatically monitors the user's access to snacks and provides eating-related sounds feedback. This tangible tool is designed to address snacking addiction in everyday life. Beyond presenting an innovative design case, the practical, hands-on data obtained through probe experiments enabled us to deepen our understanding of snacking scenarios and user needs, and to reflect on the balance of design considerations. As demonstrated by the results of the field study, real-time anthropomorphic sound feedback is effective in improving control of snacking, although Hicclip is a low-cost, simple prototype with limitations in real-world. Moreover, it is mentioned that using Hicclip could be fun, but it faces challenges in personalization and long-term use.

In the discussion, we reflected on the tangible design with automatic snacking monitoring technology, real-time sound feedback mechanism, anthropomorphic and emotional interaction design, and the application of snacking behavior data. This structure follows the main functions and design features of Hicclip, and we summarize design implications, challenges, and future design directions in each sub-direction.

6.1 Design Implications

6.1.1 Create simple, ubiquitous and seamless interactions without overburdening. The information we gathered in our user study demonstrates the advantages and disadvantages of the physical design and the monitoring approach. On the one hand, it was recognized by users that the physical interaction of the Snack Shelf requires minimal user learning costs, allowing users to feel relaxed and receptive when they initially start using it. In contrast to classic interactive systems for healthy diet management, Hicclip does not require the use of a camera or a mobile application, nor does it require manual entry of information or an operating system to manage eating behaviors, which makes users feel less stressed and more secure about the use of Hicclip in their daily routine.

On the other hand, the only point of contact for snack monitoring is the Hicclip's physical sensors, resulting in interactions that are limited to the space where the Hicclip is placed, and the recording and intervention of snacking behaviors is not readily available anywhere. In addition, the only action recognizable by the Hicclip is picking up and placing snacks from the shelf, leading to incomplete and inaccurate monitoring data. For example, the rate at which the user eats the snack is not monitored and therefore the total amount ingested cannot be recorded. In existing related studies, advanced technologies support the recognition of food and eating actions through images and sounds to quantitatively analyze the amount of intake, the speed of intake, and the nutrients consumed. In contrast to these technologies, the Hicclip approach has a large gap in terms of practical usability, monitoring accuracy and robustness. In summary, we recognize that there are trade-offs between keeping things simple and low-cost versus accurate, comprehensive interactions, and that there are different opportunities to enhance the Hicclip experience based on different concerns:

First, keeping the interaction simple enhances the usability of the physical design from a physical interaction perspective. Hicclip's affordability and design features that integrate it with everyday objects give it the opportunity to become a popular and creative interactive product. We believe that optimizing the appearance and engineering dimensions of the Hicclip is a possible way to make the Hicclip a commodity that can be used in everyday life. Examples include integrating the Hicclip's electronics into smaller snack closure clips to get rid of the shelf portion and judging pickup and drop-off by contact with the clip, or designing snack storage shelves that are more in line with home-use dimensions and adding weight sensors, etc., to monitor snacking behavior. This has the potential to create commercial value, but the sustainability and scalability of the product is small.

Second, apply IoT technology to improve connectivity and compatibility. The management of snacking behavior and the overall diet are inextricably linked, and some participants suggested that they would like Hicclip to evolve into a larger system that focuses on the overall dietary health profile. When providing design suggestions, most of the experiment participants associated it with other daily touchpoints related to eating, such as proposing the inclusion of sensors in refrigerators and lockers to jointly monitor eating behavior. Additionally, some participants wanted Hicclip to interconnect with apps to support real-time visualization and self-tracking of eating behavior data. These suggestions reflect user demand for more comprehensive and accurate diet monitoring. Relevant research has demonstrated the implementable technics of audio augmented reality in environments and objects [52]. Similar applications have been suggested in biofeedback for stress management or physical health behavior [11, 49]. Imagine Hicclip as a subcomponent of smart diet management system in the home, providing data on snacks for overall snack management and accessing data on other dietary intakes for analyzing the health of an individual's diet. IoT technology provides an application opportunity for our design to break through the limitations of a single physical touchpoint while keeping the interaction simple. The IoT technology provides an opportunity to apply our design in a way that keeps the interaction simple while breaking through the limitations of a single physical touchpoint to create a flexible and scalable diet management experience.

6.1.2 Enriching interaction mechanisms and feedback to enhance long-term user engagement. To support the immediacy and efficiency of the snacking behavior intervention and to overcome the visual occupation of the user while multitasking, the design of Hicclip features real-time audible feedback. From the experimental results, in most cases Hicclip's sound cues immediately draw users' attention to the snacking behavior and interrupt the snacking addiction. However, as time passed in the experiment, users clearly showed that their engagement and motivation to use Hicclip became low. From the participants' interviews, we analyzed some reasons for this: first, the interaction mechanism of Hicclip is set in advance, and when the monitored intake time reaches a certain value, a burping sound is triggered to interrupt the user, which is similar to a "snack clock" that restricts the user's snacking behavior. The user has no control over the Hicclip's on/off switch or customized feedback mechanism. This causes some users to get bored when they don't want to be interrupted. In this case, the user's perception of the Hicclip's sound may be similar to the annoyance of everyday noise. Second, Hicclip has only one type of feedback (containing a chewing sound and a burping sound), and after long interactions, users may lose interest. As relevant studies have shown, repetitive unvarying feedback can lead to user disengagement, especially in tasks that lack diversity and challenge. Third, Hicclip interactions are deficient in feedback closure. Established research has amply demonstrated the critical impact of positive and negative feedback on behavior change, and Hicclip does not provide positive feedback.

According to the field study, on the one hand, we learned that this design consideration helped our participants quickly adapt to using the system. On the other hand, we received some comments that the current design of sonic feedback could be undesirable for users who are enjoying healthy snacks or occasions like public spaces. Therefore, we believe that it is worthy of developing personalized sonic feedback mechanisms to offer just-in-time interventions for promoting healthy snacking patterns. There have been some predictive modeling techniques that could potentially advance the smartness of Hicclip's sonification. Indeed, there has been a great deal of research into techniques for modelling users based on the deployment of ubiquitous sensors in the context of physical activity [53]. For example, a theory-based model to compute habit strength with higher accuracy [54] could be employed to support us in developing highly personalized sonification system for snack interventions. Additionally, the robustness of the system could be enriched further with a more diversity of sensors to collect behaviors and objective eating data, for improved user modeling [35]. For instance, cameras could be embedded into food storage places to record nutrition and calorie data directly; The snack consumptions could be weighed directly using the pressure sensors.

Moreover, to enhance user engagement and motivation, gamification design also provides good direction. Existing research on healthy eating behavior change design often utilizes game design elements to motivate users to persist in tasks over time, such as breaking through levels and points. Hicclip can also make interactions more engaging by adding gamified feedback mechanisms. For example, Hicclip could provide positive audible feedback, such as applause, during periods when users maintain good habits of moderate intake.

In addition, we can enrich the sounds feedback. According to Kleinberger and colleagues [24], eating sounds can significantly influence how people perceive eating behaviors and appetite, Hence, we selected eating sounds as the basis of sound augmentations, assuming that exaggerated sound effects could be helpful to reduce users' aspiration of eating snacks. Our quantitative findings suggested the usefulness of designed sonification for improving snacking patterns. However, almost all the participants reflected that after a long period of time the sonic interactions would become boredom and thus lose its user adherence. Their feedback generally suggested that the current sound designs were too simple to be applied and thus we need to explore a more diversity of eating-related sounds for augmenting snacking experiences.

For the next step, we would suggest HCI researchers to build databases of sound augmentations that could be further integrated with eating-related sounds. One potential direction could be combining with peer pressure as a dialogue support [3, 38, 41]. E.g., one of our participants expressed that the sounds could be recorded by their friends so that the eating sounds from peers could offer mixed feeling for a more unique snacking experience.

6.2 Limitations and future study

Clearly, our study has a few limitations that the findings should be cautiously interpreted. First, there are limitations to the sample and settings of the in-wild study. Our participants only included young adults with a very small sample size. Thus, it may not be representative for the wider population, which might limit the reproducibility of our study findings. Future research should focus on a larger and more diverse user group to enhance the generalizability of the results. In addition, the evaluation results of Hicclip were limited to the setting, we only observed and recorded snacking behaviors in the indoor space where the Hicclip was placed, without analysis of the full range of dietary content and behavioral changes of the users. The short experimental period is also a factor in limiting the results. It is likely that the interaction with Hicclip had a novelty effect on participants [48]. Future work should be refining the design of sounds and tangible interactions to enhance user engagement over longer periods of time to test the effectiveness of the proposed sonification in promoting healthy snacking.

In addition, the prototypes of Hicclip still lacked some technical rigorous. The robustness of the system design should be improved further. The current insufficient consideration of design and technology also led to experimental errors. Twice during the experimental cycle of Hicclip mute, participants forgot to put the snacks back after stopping eating, resulting in the recorded snack eating time far exceeding the actual snack intake time. In future work, with the improved technical components of the new Hicclip prototype, the rigidity of the data collection could be optimized with more quantitative, objective measures to evaluate the effectiveness of augmented eating sounds in influencing people's snacking behaviors.

Furthermore, there is a considerable research space for designing augmented eating sounds to change snacking behaviors. Our study only used specific sound elements as feedback for snacking behaviors, where participants perceived the two sounds in a various way that might guide the future sound interaction designs. For example, the multidimensional elements of sounds have potential impact on eating perception [24]. Future research could delve deep into whether and how the type, frequency, or volume of sounds could have varied or consistent effects on the perception of i.e., fullness.

Lastly, it is imperative to reflect on the ethical considerations inherent in sensor-based interventions for healthy snacking, a domain marked by significant personal and sensitive concerns. The use of such technologies must be approached with heightened diligence to respect individual privacy and the personal nature of eating habits. Our design of Hicclip, while aimed at promoting healthier snacking behaviors, raises important ethical questions about the extent to which technology should influence personal choices and habits. As we advance our research, incorporating a robust ethical framework will be essential to guide the development and implementation of such interventions. This will involve engaging with ethicists, healthcare professionals, and the wider community to ensure that our technological solutions align with ethical standards and user expectations.

7 CONCLUSION

In conclusion, this paper shows empirical evidence on incorporating augmented eating sounds as sonification to intervene daily snacking behaviours. The quantitative findings suggest decisive effects of Hicclip on reducing mindless snacking and the qualitative insights highlight its benefits in supporting self-regulation, long-term adoption, and eating-related health tracking. This paper contributes to the body of knowledge in HFI that utilizes sonic interactions to promote healthy and sustainable eating.

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