GastroConcerto: Towards Designing Auditory Dining System to Enrich Chefs' Culinary Practices

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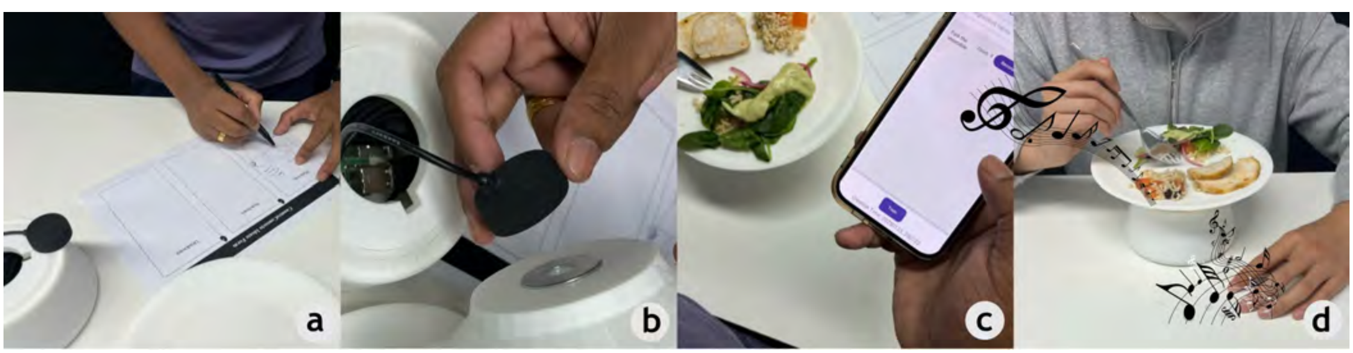

Figure 1: The workflow of using GastroConcerto for chefs. (a) The chef ideates a sonic dish design. (b) The chef attaches the contact microphone beneath a chosen tableware. (c) The chef uses GastroConcerto's app to link sounds with their preferred ingredients while saving the configuration in the data library for future use. (d) The diner savors a sonic dish created by the chef.

Abstract

Sound plays a crucial role in shaping diners' perceptions and enhancing the dining experience. Recognizing this, designers have started to integrate auditory elements into interactive interfaces that connect diners with food. However, how chefs incorporate sound into their culinary practices remains underexplored. To bridge this gap, we introduced *GastroConcerto*, an auditory dining system that allows chefs to link specific sounds with ingredients, enabling the creation of unique sonic dishes. Our ultimate goal is to enrich chefs' creative repertoire through novel auditory interactions.

CCS Concepts

• **Human-centered computing → Interaction design**.

Keywords

Human-food interaction, auditory interface, chefs' culinary practices

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1 Introduction

Culinary creativity, "as an expression of the chef's inner world [28]", manifests through food [38]. Chefs traditionally innovate by experimenting with ingredients – through arrangement (e.g., plating [41]), sensory exploration [62], and reconfiguration (e.g., molecular gastronomy [5]) – to craft curated specific themes and experiences. While most current culinary innovations integrate various modalities (e.g., visual [11, 47] and tactile [46]) to enhance engagement, sound as a sensory component in gastronomy has yet to reach its full potential.

Auditory stimuli during dining, often described as "the forgotten flavor sense" [45], can enrich dining experiences [40], altered sensory perception [44], and influence eating behaviors [48]. For example, high-pitched sounds are associated with sweetness and sourness, while low-pitched sounds correlate with bitterness [18]. This sound-taste cross-modal correspondences have spurred interest in hospitality, with music-themed restaurants adjusting soundscapes (e.g., volume, tempo) to influence eating pace [42] and blindfolded restaurants leveraging sound to heighten sensory awareness [2]. These insights have increasingly captured the attention of Human-Food Interaction (HFI) designers [8, 10, 14, 35], leading to the integration of auditory elements into food interactions.

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However, prior HFI research has mainly focused on diner-centric perspectives [11, 14, 57, 58]. The integration of auditory elements are often resided with stakeholders such as interaction designers or restaurant founders, limiting chefs to creating dishes within predefined auditory frameworks [24]. This oversight risks reinforcing the perception that chefs cook for themselves rather than diners [60]. To bridge the gap and explore how chefs can take ownership of auditory interaction design, we conducted a formative study with 7 professional chefs identified four key challenges in integrating auditory interaction into culinary practices, informing the design goals for *GastroConcerto*. Therefore, our contributions are: (1) A system *GastroConcerto*, comprising a mobile app, a sensing hub for processing acoustic signals, and three different dining containers. It utilizes contact microphones to capture the acoustic signals from ingredient processing on containers, enabling chefs to establish sound-ingredient correspondences. (2) Four approaches to curating sonic dishes (i.e., a sound library, uploading, sonification, and AI music generation). We aim to empower chefs to assign specific sound generation options, enriching their culinary practices.

2 Related Work

2.1 Culinary Support Systems for Chefs in HFI

HCI researchers are increasingly interested in developing systems to support creativity using AI [32], interactive technologies [1, 56], and information systems [34] to aid practitioners in fields like education [26, 27], painting [36], etc. In the culinary domain, creativity involves chefs crafting meaningful food experiences through conceptualization, preparation, cooking, and presentation, ultimately realized through diners' perceptions [37]. With advancements in culinary education [12, 21], chefs are now expected not only to innovate in creating delicious meals but also in aesthetically compelling ways [28]. This has inspired HFI research to explore culinary support systems to enrich their creativity.

Culinary support systems have been proposed to assist chefs during conceptualization (e.g., using levitation technology [51], 3D food printing [54], shape-changing foods [50]) and dish presentation (e.g., using interactive audio-visual performances [19], fluid trajectory arrangement [9, 11], soundscape experience [43]). However, these designs face limitation: (1) chefs' creativity is constrained by predetermined system content [19, 43]; (2) many designs remain exploratory [9, 11, 50, 51, 54] and lack integration into culinary practices; (3) they often rely on specific food substrates (e.g., pastes [54], droplets [9, 11, 51]); and (4) while chefs often arrange diverse ingredients to craft dining narratives [13, 17], most systems are limited to unidirectional displays [9, 11, 19, 43, 51], lacking flexibility to synthesize technologies with varied ingredients for unique culinary expression. In response, van Doleweerd et al. [50] conducted participatory sessions with chefs to explore integrating shape-changing food into culinary practices. This highlights the opportunity to collaborate with chefs in developing auditory interactions that enrich their creativity [53].

2.2 Auditory Interaction in HFI

HFI researchers have increasingly explored applying auditory stimuli to transform dining experiences [40], shifting from passive auditory enjoyment (background music) to active sound interaction (sounds responding to eating actions).

First, edible auditory interfaces focus on food properties like dryness [6, 23] and moisture [57]. For example, "FoodSkin" used edible gold foil circuits on cookies to trigger sounds by detecting resistance and capacitance changes [23]. While promising, such designs require external circuits and are limited to specific food substrates, challenging the integration into chefs' culinary practices. Second, dietary tableware interfaces include: (1) utensils sensitive to eating trends (e.g., IMU-sensing cutlery [22]) and states (e.g., capacitive-sensing straws [58]). However, these often fail to showcase chefs' creations or require direct food contact, weakening the connection between auditory experiences and eating. This limitation also applies to head-mounted sensors capturing eating actions [25, 59]. (2) Dining containers, such as weight-sensing plates driving audiovisual performances [63] or "Gamelunch," which maps eating sounds to interactive audio [39]. While these support culinary exhibitions, empirical research on auditory interactions to enhance chefs' practices remains limited. We categorize these approaches into three groups based on eating-action sensing (Table 1).

Table 1: Three sensing approaches from prior sound-related HFI, the brackets indicating the auditory interaction mode of each work.

Eating-Action Sensing Approach	Research Name (Auditory Interaction Mode)
Capacitive Sensing	SonicStraw [58] (Uploading), WeScream! [57] (Sonification), EducaTableware [22] (Uploading), FoodSkin [23] (Sonification)
Motion Sensing	Chewing Jackey [25] (Uploading), FunEat [63] (Uploading), GustosonicSense [59] (Uploading)
Acoustic Sensing	Gamelunch [39] (Sonification)

By reviewing previous work on auditory interfaces, *GastroConcerto* extends prior diner-centered interaction mode toward chef-driven creativity for sonic dish orchestration. While inheriting sound generation methods such as uploading and sonification, traditionally controlled by interaction designers and restaurateurs, we empower chefs with full ownership over crafting their preferred sounds to synthesize with their multi-sensory culinary creations. In particular, we establish an innovative sound-ingredient pairing approach, integrating it with the dynamic evolution of dish narratives to create meaningful sensory dining experiences.

In summary, we identify a research opportunity in HFI to develop auditory culinary support systems for chefs, leading to the question: *How do we design an auditory dining system to enrich chefs' culinary practices?*

3 Formative Study

Our exploration of designing an auditory dining system to enrich chefs' culinary practices is grounded in reflective practice [16], which emphasizes the value of purposeful design activities. To inform the system design, we conducted a formative study [3] with seven professional chefs. The study had two main objectives: (1) to understand their experiences with culinary interactive technologies, thereby identifying challenges for integrating auditory interactions in their culinary practices; and (2) the insights gathered from our discussion that led to the design goals, thus ensuring the perspective of chefs is adequately reflected in our system's development.

3.1 Method

Seven chefs (age: M = 28.29 years, SD = 3.2; 5 men, 2 women) were recruited via social media and word-of-mouth. All participants had extensive culinary experience (M = 6 years, SD = 3.61). Participants were selected based on their prior experience with interactive technologies and their interest in enhancing culinary creativity through auditory interactions (details in table 2).

We provided participants with slides and videos introducing state-of-the-art HFI research to help participants develop a conceptual understanding of HFI, in particular about the perception of auditory interactions in dining scenarios. We conducted 30-minute semi-structured interviews with each participant [31], consisting of two key components: (1) Open-ended discussion: Participants reflected on their culinary experiences and challenges with interactive technologies while sharing their approaches to experiment dish innovation, and discussed their perspectives on integrating auditory interactions into the culinary practice. (2) Design elicitation investigation: Participants were encouraged to ideate new systems for auditory interaction from their culinary experience. Notes were taken during each interview, and the audio was recorded to transcribe. Two researchers independently read the transcripts three times to familiarize themselves with the data and coded the responses. The results of the analysis were identified through collaborative discussions.

3.2 Challenges in integrating auditory Interaction in chefs' culinary practice

3.2.1 Auditory interactions may increase time costs. All chefs perceived the incorporation of auditory interaction into their culinary practice as potentially time-intensive. This may arise from several factors, including distractions (P3), training (P3, P5), managing customer flow (P4), added complexity (P1, P4, P6), and adapting to menu changes (P2, P6). Therefore, chefs emphasized the importance of simplicity requirements. P7 explained, *"If I need to control an app or system during food preparation, it must be convenient, [...] with quick and simple shortcuts."* Meanwhile, P2 shared her experience with audio-visual interactive projections during seasonal changes: *"Every time I change the menu, I need to replace and edit all the animations to match my dishes [...] This is so costly."*

3.2.2 Exposed electronics may detract attention from the food. Three chefs expressed concerns about the exposure to electronic components, which detracted from their interest in applying these technologies. P7 explained, *"Technology shouldn't become a gimmick [...]*

Table 2: Participant demographics.

Code (Age, Gender)	Occupation	Food-related experience	Interactive technology-related experience
P1 (24, Male)	Bartender	3 years of experience crafting unique cocktails	Frequently uses Apple Watch voice control to time the shaking process during cocktail preparation
P2 (32, Female)	Head chef	10 years of experience in fine dining, including providing personalized customer service and creating customized dishes	Operated a restaurant featuring interactive audio-visual performances before
P3 (26, Male)	Italian restaurant chef	2 years of experience in a western restaurant, involved in preparing pasta, pizza, and salads	Although not used in professional settings, had prior exposure to interactive machines in shopping malls, such as those used for making juice and cotton candy.
P4 (28, Male)	Barista	8 years as a coffee shop owner, focused on coffee product development	Regularly uses automated coffee machines to adjust the grinding, extraction, and dosing of coffee beans.
P5 (27, Male)	Pastry chef	7 years of bread and pastry making experience	Participated in user studies for HFI systems, engaging with 3D food printing technologies before
P6 (28, Female)	Barista	2 years of experience in a coffee chain, included preparing coffee and serving customers	Regularly uses automated coffee machines to adjust the grinding, extraction, and dosing of coffee beans.
P7 (33, Male)	Baking and pastry chef	10 years of pastry research and development experience, covering launching new products in stores and training employees	Habitually employs automated dough mixers to control humidity, duration, and temperature for crafting doughs with varying gluten strength

it should highlight the food itself. [...] I [hope my customers] experience this interaction naturally, without it feeling too deliberate."

3.2.3 Hygiene and cleanliness concerns. Four chefs expressed concerns about hygiene and food safety associated with integrating interactive technology. P3 emphasized, *"[We need to] work while wearing masks and hats. If we use these devices, [...] they might expose us to bacteria and add an extra cleaning burden."* To address this concern, P2 envisioned a structure for future systems: *"Our utensils need a high-temperature sterilization [...] so we could design a platform, triggering sounds by lifting cups."* This suggests the need to separate sensing components from dining tablewares to ensure hygiene and reusability.

3.2.4 Limited sound expertise may hinder curation. All Chefs proposed various visions for auditory interaction design, viewing sound as a low-cost yet customizable interactive feature. However, due to their lack of relevant expertise, they expressed that there might be a benefit in automated sound orchestration (P3, P4), an extensive sound library (P2, P6, P7). As P4 explained, *"If there were an AI system, I could simply tell it through the voice commands to add any elements to my dish [...] it would significantly reduce my workload."*

3.2.5 Potential for messy sound experiences in public spaces. P6 raised concerns about "chaotic" sound interactions that could occur in multi-diner scenarios, she remarked, *"Some guests just want to quietly read a book at the café [...] loud public sounds might disturb them."* P1 added a more accurate explanation, *"These sounds should be limited to a small range so only nearby diners can hear them."*

3.3 Design Considerations for developing the *GastroConcerto* System

3.3.1 Design a Sensitive, Isolatable, and Non-Contact Sensing Hub. It enables chefs to experiment with and assign diverse auditory interactions to food, moving beyond prior HFI research limitations to single food types [7, 51, 57]. (1) *High Sensitivity*: The hub must accurately capture real-time data streams of eating actions involving specific ingredients at a high sampling rate. (2) *Environmental Isolability*: It must resist interference from other environmental signals (e.g., conversational noise, other dining activities). (3) *Non-Contact Sensing*: To enhance hygiene, the system should utilize non-contact sensors to detect data streams from eating actions.

3.3.2 Design for Real-Time Orchestration and Memory Functionality. Integrating auditory interactions into the culinary domain introduces inherent time costs, as new interaction modes often bring unfamiliar qualities [20, 52], inevitably disrupting the initial balance [49]. Thus, we aim to develop a portable and user-friendly applications [29]. (1) *Real-Time Orchestration*: Inspired by real-time AI interaction [15, 55], we aim to enable chefs to orchestrate culinary expression through sonic dishes with immediate responses and on-the-fly adjustments. (2) *Memory Functionality*: First, Chefs can use the software for pre-cooking experimentation, saving results for later use. Second, memory functionality enables auditory presentations to be bound to specific dishes, adapting to seasonal menu rotations.

3.3.3 *Design a Diverse, Modular, and Food-Grade Dining Containers.*

Food containers have long been a medium for chefs to showcase their culinary creativity and a key focus in HFI research [22, 39, 57, 63], offering affordances that support diverse eating actions from food preparation to consumption [30]. (1) *Diversity*: Accommodate a variety of food types and chef specialties. (2) *Modularity*: Allows easy assembly, disassembly, and cleaning for sustainable reuse. (3) *Food-Grade Materials*: Ensure safety with non-toxic, high-temperature-resistant materials.

3.3.4 *Design a Convenient, Personalized, and Automated Auditory Interaction.*

This design aims to transfer sound orchestration ownership to chefs while providing automated tools to bridge gaps in audio expertise. (1) *Multi-sound generation options*: Prior HFI research primarily focused on uploading and sonification (as shown in Table 1), limiting interaction to single modes. Our system integrates diverse auditory interaction modes, including AI-generated music, to cater to chefs' varied needs. (2) *Two modes of sound enjoyment*: The system offers both speaker and headphone options, allowing diners to choose between communal and private enjoyment of sonic dishes.

4 *GastroConcerto* System: Design and Development

We present *GastroConcerto*, a novel prototype designed to integrate auditory interaction into chefs' culinary practices (Figure 2). Rather than positioning this prototype as a final product, we envision it as a foundational step toward future designs that seamlessly integrate auditory interaction into chefs' culinary practices.

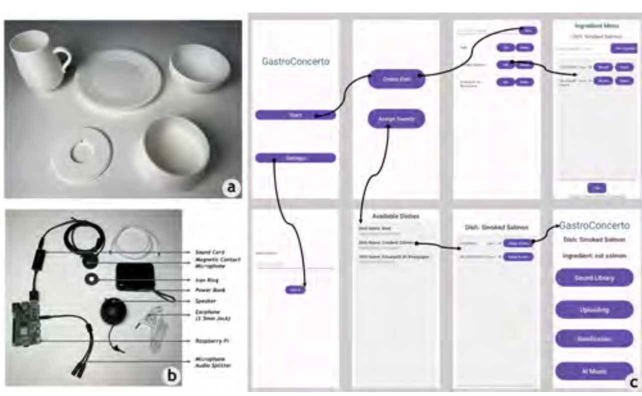

Figure 2: The GastroConcerto system overview. (a) Three 3D-printed dining containers and a mount for hardware components. (b) Overview of the hardware components. (c) The mobile application interface.

4.1 Designing a Sensing Hub for Capturing Ingredient Operations through Acoustic Signals

Through the review of auditory interaction techniques in HFI (Table 1), we experimented with five types of sensors and implemented these in the initial auditory interaction prototypes (Figure 3). Six participants (4 male, 2 female, none non-binary or self-described; M = 22.83 years, SD = 1.6) were invited to engage with these prototypes (details in Appendix A).

	Touchscreen	Capacitive Board	IMU Sensor	Geophone	Contact Microphone
Sensitivity	●●○○○	●●●○○	●●●●○	●●●●○	●●●●●
Isolability	●●●●●	●●●●●	●○○○○	●●○○○	●●●●○
Non-contact	○○○○○	○○○○○	●●●●●	●●●●●	●●●●●

Figure 3: Exploring the Potential of Five Sensors: Touch Screen, Capacitive Board, IMU, Geophone, and Contact Microphone

4.1.1 *Capacitive Sensing.*

We incorporated two types of capacitive sensors into the prototypes to trigger auditory interactions: (i) an iPad-based capacitive touchscreen, and (ii) simple plateware equipped with an Adafruit capacitive development board and 5mm-wide copper foil single-sided adhesive tape. These sensors enable precise detection of eating actions occurring on (i) and (ii) without interference from external factors. However, both designs require sensing elements to be directly connected to the containers, complicating subsequent cleaning. Additionally, they impose strict requirements on the moisture content of the food: overly dry foods could not be detected, while excessively moist foods caused confusion or delays in sound display.

4.1.2 *Motion Sensing.*

We explored: (i) an IMU sensor in an iPhone, used to detect changes in z-axis acceleration, and (ii) a Geophone vibration sensor. These sensors demonstrated sensitivity to motion changes and potential for non-contact applications. However, these sensors lack robust isolation capabilities, potentially due to the following factors: (1) the IMU sensor must remain positioned parallel to the platewares. If the sensor rotates during the dining process, it can easily cause auditory confusion, leading to a sensory overload experience. (2) the data from Geophone was always interfered by noise from footsteps or from the table impacts. Thus, we 3D-printed a platform that securely held the Geophone in an inverted position, enabling it to detect eating actions on this platform. However, inverting the geophone often caused abnormal signal fluctuations. This may have occurred due to gravitational forces slightly displacing the internal suspension springs, leading to signal misalignment in vibration measurements. (3) both sensors demonstrated low sensitivity to subtle eating behaviors. Diners often had to exert significant effort to trigger sound changes, potentially introducing unnecessary strain to the dining experience.

4.1.3 *Acoustic Sensing.*

We used a contact microphone to detect eating actions through acoustic signals, which demonstrated high sensitivity. It exhibited perfect isolation capabilities, remaining largely unaffected by human voices. We mounted it on the outer wall of a plate, enabling the sensor to remain separate from the food. However, we observed vibrations on the table occasionally interfered with the signals. So we placed rubber studs beneath the container.

We finally selected the contact microphone to achieve our objectives and utilized the Raspberry Pi as a computational hub to proceed with rapid prototyping and interaction. Additionally, the contact microphone we selected features magnetic properties, allowing for easy attachment from the dining container through magnetic adhesion.

4.2 Designing the Mobile Application

We developed our mobile application using Android Studio. The application supports real-time data collection, model training, and interaction (Figure 2(b)). The specific functionalities include:

4.2.1 Creating a Dish. Upon entering the homepage, chefs first navigate to input the current local network IP address, establishing a connection with the Raspberry Pi. Next, they revisit the homepage to select "Create Dish," which allows them to input the name of their dish such as, "Smoked Salmon."

4.2.2 Establishing sound-ingredient correspondences within the dish. Chefs can identify potential sound-ingredient correspondences within their dishes such as, triggering auditory interactions during cutting salmon or dipping it into sauce, provided that the acoustic signals generated by these actions are captured by the sensor. This process involves two steps: (1) Acoustic data collection: The chef clicks "Record" to capture the data in the form of a .wav file for training the machine learning model. We used a fixed-size deque as a buffer to store the five most recent frames, providing context prior to the action and ensuring event completeness. We implemented a peak-based sliding window method [61] for segmenting eating actions. As the one-frame sliding window moves, audio data exceeding the peak threshold indicates an action event. The system stores the buffer data to include the preceding audio context of the action. If the peak threshold is not exceeded, the window advances to the next frame. After detecting an event, a fine-grained sliding window of 0.5x frame size is applied to detect amplitudes falling below the release threshold, refining the event's start and end points. If the duration below the release threshold exceeds 0.2 seconds, the action event is considered complete. The thresholds are determined through our experimentation. Every correspondence is required to be performed 15 times. (2) Acoustic data analysis: We employed a Random Forest model, as prior research has demonstrated it to be the best-performing machine learning model for classifying eating actions [59]. During training, key audio features are extracted from both the time and frequency domains, with each audio segment represented as a fixed-dimension feature vector. Finally, the trained model and a normalizer are stored within the dish file.

4.2.3 Assigning sound to each correspondence. After completing the aforementioned steps, chefs can assign sounds to each correspondence within the dish. The dish status will display "Completed" when the dish is ready or "Pending" if the model has not yet been trained. Once marked as "Completed," chefs can click "Allocate Sounds" to assign sounds to each correspondence. To support this process, we have prepared four types of auditory interactions, detailed in Section 4.4.

4.3 Designing Three Dining Containers

We created plateware, bowlware, and drinkware to support the culinary practices of chefs from various professions. At the base of each container, we designed a recess to house an iron ring, enabling the manual attachment of magnetic contact microphones while ensuring the containers are easy to clean and sterilize. Currently, we used PLA material for 3D printing, but we plan to adopt ceramic 3D printing for container fabrication to better meet food safety requirements. For the design of the sensing hub, our primary requirement was to accommodate all electronic components in a way that maintains aesthetic appeal and does not interfere with the primary dining experience. We also utilized silicone rubber material beneath the *GastroConcerto* to achieve effective isolation. Additionally, we implemented a detachable partition to connect the sensing hub and the dining container. This partition features a circular opening that facilitates the connection of magnetic contact microphones from the sensing hub to the containers.

4.4 Four approaches to integrate auditory interaction

We developed four approaches to integrate auditory interaction: (1) *Sound Library*: Drawing on the PLEX framework [33], which categorizes a wide range of experiences, we developed a library of 22 vivid sound effects. This mode is designed to imbue various food types (e.g., liquid, solid, crunchy) with distinct character. (2) *Uploading*: This approach allows chefs to upload their preferred music tracks to the *GastroConcerto* system and associate them with each ingredient in the current dish. (3) *Sonification*: This approach transforms the rich acoustic signals generated from each ingredient into melodious MIDI notes. Greater amplitudes are mapped to higher pitches, generating various MIDI notes within a fixed octave range. Higher frequencies correspond to louder and more intense velocities, while greater energy produces longer note durations, resulting in more lingering sounds when the energy within a time window is higher. We provide 128 MIDI tones, including options such as piano, percussion, etc, allowing chefs to tailor the auditory experience to their preferences. For diners who prefer private interactions, we have implemented panning, which immersive and dynamically shifts audio between the left and right channels in headphones. (4) *AI Music Generation*: We leverage the deep learning framework RAVE to generate diverse music models trained on various music style datasets [4]. These models can produce audio without the need for pre-recorded music and enable users to adjust the timbre and rhythm according to input music segments. This approach significantly enhances the efficiency and quality of auditory interaction. In this mode, we provide eight pre-trained models to support chefs in creating sonic dishes.

5 Conclusion, Limitations and Future Work

In this paper, we introduce *GastroConcerto*, a culinary support system developed through auditory interaction. This work draws insights from the relationship between chefs' everyday behaviors and interactive artifacts. Specifically, through our formative study and design process, we identify four key facets that interaction designers should consider when developing new interactive artifacts to enhance chefs' culinary practices: (1) *Temporal*: Chefs' sensitivity to time in their culinary workflows. (2) *Attention*: The artifact should not interrupt chefs' workflows. (3) *Usability*: The containers should be easy to clean and reuse. (4) *Inclusivity*: The system should accommodate chefs with varying expertise. Building on these insights, we empower chefs with ownership over curating auditory interactions in dining experiences by establishing ingredient-sound correspondences. Our aim is to explore how auditory stimuli can function as a novel "ingredient," thereby enriching culinary practices and potentially driving transformative changes in the culinary arts industry. Meanwhile, we acknowledge several limitations of this work. First, the materials of the dining containers and the refinement of auditory aesthetics could be improved for better practical implementation. Second, we have not yet conducted an empirical study to observe chefs' interactions with the GastroConcerto system in real-world settings. This limitation prevents us from fully understanding the unique cross-sensory correspondences between sound (e.g., attributes, duration, rhythm) and different ingredients, as well as the cultural and personal interpretations that may act as intriguing catalysts in shaping these relationships. Therefore, we plan to refine this prototype in future iterations and engage with professional chefs to foster novel food creations, explore chefs' creative processes in orchestrating sonic dishes, and investigate diners' corresponding sensory experiences. We hope this work could pave the path for interaction designers who are interested in develping novel interactive systems for culinary experts.

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A APPENDIX

A.1 Participants in the sensing exploration phase

Table 3: Participant demographics.

Pseudonym	Age	Gender	Occupation
Caleb	24	Female	Master student
Ethan	24	Male	Master student
Ryan	23	Male	Master student
Jordan	24	Male	Master student
Aria	22	Male	Undergraduate student
Lila	20	Female	Undergraduate student