VOLUME 8 ISSUE 2

The International Journal of

Design in Society

Auditory User Interface Design

Practical Evaluation Methods and Design Process Case Studies

MYOUNGHOON JEON

COMMON GROUND

DESIGNPRINCIPLESANDPRACTICES.COM

THE INTERNATIONAL JOURNAL OF DESIGN IN SOCIETY
www.designprinciplesandpractices.com

First published in 2015 in Champaign, Illinois,
USA by Common Ground Publishing LLC
www.commongroundpublishing.com

ISSN: 2325-1328

The International Journal of Design in Society
is peer-reviewed, supported by rigorous processes of criterion-referenced article ranking and qualitative commentary, ensuring that only intellectual work of the greatest substance and highest significance is published.

Auditory User Interface Design: Practical Evaluation Methods and Design Process Case Studies

Myounghoon Jeon, Michigan Technological University, USA

Abstract: There are many guidelines and standardizations for graphical user interfaces (GUI), whereas there is relatively little research on auditory user interfaces (AUI). The goal of this paper is to present a framework, evaluation methods, and procedures of AUI design. The paper delineates how AUIs can be designed more scientifically, by iterative participatory design processes, going beyond individual designers' artistic inspiration, which suggests AUI designers being a practitioner-scientist. First, taxonomy of AUI design is provided. Then, methods of cognitive and affective mappings for AUI design are described, followed by details of processes and design solutions for case studies. This paper aims to help practitioners and researchers apply diverse methods to their design, and to facilitate communications about AUI in the design community.

Keywords: Auditory User Interfaces, Cognitive and Affective Mappings, Design Process, Evaluation, Participatory Design

Introduction

For decades, an increasing awareness of the limitations of visual interfaces has spurred research on sound as a viable mode of information display (Kramer 1994). If implemented well, the use of sound can lead to more accessible interfaces (Nees and Walker 2009) for users with temporary or permanent vision loss (e.g., Edwards 1989; McGookin, Brewster, and Jiang 2008) and users with normal vision (e.g., Palladino and Walker 2008; Jeon and Walker 2009). When it comes to evaluation methods and processes of sound design, using an analogy of graphic user interfaces (GUIs) might be a good starting point (Yalla and Walker 2007). In that translation process, however, care is needed for optimal implementation of auditory user interfaces (AUIs). For example, a simple conversion of text into speech may not be sufficient (Edwards 1989). An optimum approach is required for AUIs to reflect auditory-specific characteristics (Glinert and York 2008). Even though auditory research has consistently grown, there are still few resources available for the reference of the auditory-specific research methods or design guidelines (see recent exception, Hermann, Hunt, and Neuhoff 2011).

This paper introduces AUI research methods and overall procedure of AUI projects. However, this paper does not cover thorough experimental concepts or exhaustive evaluation methodologies. Instead, the paper selects immediately applicable methods with necessary information – when to use, how to conduct, how to report results, pros & cons, and practical tips in the application settings. Not only AUI designers, but also other designers and researchers are expected to benefit from the methodologies described here and apply them to their own design research. The paper begins with an evaluation method "bootcamp" to provide the basic tools. Then, the paper outlines two industry projects for more concrete and entire processes of AUI design.

Components of Auditory User Interface (AUI) Design

Auditory user interfaces can be defined as "the use of sound for part or all of the display of system variables and other information, usually including information about the details of the objects involved or the underlying process." (Walker and Kramer 2006, 1022). For more detailed

The International Journal of Design in Society
Volume 8, Issue 2, 2014-2015, www.designprinciplesandpractices.com, ISSN 2325-1328

definitions of auditory displays and AUIs, see (Walker and Kramer 2006; Hermann 2008). Literature (e.g., Kramer 1994; Peres et al. 2008; Brewster 2008) has addressed advantages (eyes-free, rapid detection, alerting, orienting, backgrounding, etc.) and drawbacks (low resolution, lack of absolutes, annoyance, interference with speech, no persistence, etc.) of AUIs. Thus, this section briefly recapitulates the components of AUI: "Auditory," "User," and "Interface."

Auditory: AUI designers create and manipulate auditory entities, including non-speech sounds: earcons (Blattner, Sumikawa, and Greenberg 1989) (e.g., short musical motives such as "Ding-Dong"), auditory icons (Gaver 1986) (e.g., representative part of the event/object sounds such as camera shutter), music (e.g., background music of the idle state), and warning signals (e.g., user or system errors); and speech sounds: voice guidance or speech recognition interaction flow.

User: In general, user, task, and environment analyses are necessary elements in system design. In this line, AUI designers consider users' musical expertise, familiarity with auditory displays, and sight and hearing abilities (Peres et al. 2008). AUI designers are also required to understand target users' preference about sound quality and its parameters. Because music and sound have a strong impact on emotions (Kenealy 1988; Mayer, Allen, and Beauregard 1995; Panksepp and Bernatzky 2002; Stratton and Zalanowski 1991), they also need to understand emotional mechanisms of sound (Juslin and Västfjäll 2008; Juslin et al. 2010) and carefully choose emotional color of sound, which might influence a product (or brand) image.

Interface: Because AUI design belongs to user interface design, it involves not only the design of ring tones or feedback beeps, but also a systematic plan and application of sounds to the user interface. Therefore, AUI designers are required to fully understand the specifications and functions of that particular interface and usage scenarios. To this end, task analysis or function analysis is usually conducted. When sounds are applied to the actual product, their quality can easily change due to hardware materials. Hence, hardware specifications are also AUI designers' concern.

In sum, AUI design involves a plan, analysis, creation, evaluation, and management of the product sounds. The outcomes of AUI design should be adequate for users' needs and preference, product functionality, and its brand image. Then, how can we effectively and efficiently assess those aspects? The next section discusses AUI evaluation metrics and provides participatory design methods – preference mapping, function mapping, and emotion mapping – that practitioners and researchers can easily apply and expand for their design purposes.

AUI Evaluation Methods

Faste and Faste (2012) define design research as the investigation of knowledge through purposeful design. In the same vein, if we agree that sound design is a purposeful mapping between sounds and meanings or making organized sounds (e.g., panel discussion at ICAD 2012) from the semiotics perspective, all the processes of mapping and organizing sounds could belong to design research. When design research is conducted in the AUI domain, end users can also participate in that mapping process in various ways. Instead of providing generic experimental processes and considerations for AUIs in academia (e.g., Bonebright and Flowers 2011), here, I focus more on practical evaluation methods and processes.

Metrics and Questionnaire for AUI Evaluation

Researchers and practitioners can choose evaluation measures relying on user characteristics, task type, and task environment. It is important to apply multiple metrics to draw more comprehensive implications. Even though researchers point out that aesthetics and annoyance issues are more important in AUIs than in GUIs (Brewster 2008; Kramer 1994; Nees and Walker 2009), research has focused on performance (e.g., accuracy, learnability, or reaction time).

Nowadays, the importance of the subjective acceptance and preference of user interfaces has been rapidly increasing in user experience design circles. For example, Norman (2004) has stressed the importance of visceral design and proposed that an attractive and natural design can improve usability as well as affective satisfaction (Norman 2004, 2007). An early study suggested that the nature of sound aesthetics is independent of performance outcomes (Edworthy 1998). That is, users might turn off an annoying sound even though the presence of that sound enhances system performance. Likewise, system sounds can improve the aesthetic experience of an interface without changing performance (Nees and Walker 2009). Therefore, it is evident that developing subjective evaluation metrics as well as objective metrics for AUIs is crucial to the success of the entire system. From this standpoint, a variety of dependent measures for AUIs have been surveyed from literature and design experiences in industry and academia.

Subjective evaluation measures can be categorized as several subcomponents (e.g., preference, workload, perceived performance, etc.). For subjective evaluation, the Likert-type user rating scale is frequently used (e.g., in the seven-point Likert-type scale, 1 is "not at all", 4 is "neutral", and 7 is "very much" or 1 is "frustrating" and 7 is "satisfying" (Andersen and Zhai 2010)). For example, mobile phone studies (Marila 2002; Helle et al. 2001) have included preference metrics: first impression, annoyance, aesthetical/musical judgment, opinion of the lengths of sounds, suitability to corresponding functions, effect of usage, and usefulness. Adding AUIs not only increases preference but also decreases users' subjective workload. In subsequent experiments, sonically enhanced buttons and scrollbars reduced subjective workload as compared to their silent counterparts in a desktop (Brewster 1997) and a handheld computer (Brewster 2002). Recent work with spearcons (compressed speech, Walker et al. 2013) and spindex cues (phonemes of the first letter of the spoken item, Jeon, Walker, and Srivastava 2012) began to study the subjective improvements of AUIs more systematically, including preference and workload as well as performance measures. Specifically, in a dual task context such as navigating a menu while driving, all sound conditions reduced subjective workload compared with the no sound condition (Jeon et al. 2009). Additionally, perceived performance of the use of sounds can be measured. For example, Jeon and Walker (2011) used "effective", "functionally helpful", and "useful" as perceived performance scales in their spindex research. Researchers can combine as many variables as possible depending on their research purpose and expected outcomes (see Table 1).

Table 1: Metrics Used in the Evaluation of Auditory User Interfaces

Type of Metrics	Dependent Measures	Methods
Objective Metrics	Efficiency	Reaction Time
	Accuracy	Number of Errors
	Learning Rate	Reaction Time/Accuracy Change according to Block
Subjective Metrics	Perceived Performance	How effective/helpful/useful is this sound? opinions of the length of the sound
	Preference	How likely/fun/appropriate/wonderful/satisfying/stimulating is this sound? Would you like to have these sounds in your own device?
	Annoyance	How annoying/distracting/irritating/terrible/frustrating/dull is this sound?
	Aesthetics	How aesthetic is this sound? What is your first impression from this sound?
	Workload	e.g.,) NASA-TLX (mental demand, physical demand, temporal demand, performance, effort, and frustration)

Preference Mapping: Choosing the Best Design and Running a Chi-Square

Sometimes target populations are not able to complete a questionnaire (e.g., children, people with disabilities, etc.) or the results may not reflect users' preference well (e.g., low response rate on a survey). One of the simple but powerful ways to make a design decision is to directly ask target users about which design works best for them.

Researchers can devise several (4-5) AUI alternatives and have participants choose their favorite one. Of course, the most frequently selected sound would be the best choice. To report a statistical result for this difference of the frequency of the choices, researchers can run a Chi-square analysis with this assumption: "If there is no salient preference among design alternatives, all choice frequencies are to be equal across designs."

Table 2: Data Set Example

Design Alternatives	Observed Frequency
Design A	8
Design B	6
Design C	1
Design D	1
Design E	0

When we assume the result of the choice as in Table 2, here is an example of the report: "For the best choice among the five alternatives, there were clear preferences. Eight people found the design A was the best and six people preferred the design B most. Only one participant each chose the design C and the design D as their best. No one preferred the design E. This distinction was statistically confirmed by analyzing the frequency of the choice: Actual frequencies were significantly different from the case in which all frequencies are equal, X2(3, 16) = 9.50, p < .05."

Note that the Chi-square result shows that there is a statistically significant trend in choices. However, it does not necessarily tell us about details of the differences. In the example above, we can report that participants prefer A and B over C, D, and E. However, it does not provide us with the difference between A and B.

Function Mapping: Conducting a Sound Card Sorting Task

Figure 1: Image of the Sound Cards (Left) Used in the Card Sorting Task (Right)

With a subtle difference from users' preference, we need to assess if the sound represents intended functionality. The card sorting task is a traditional Human Factors technique, employed to assess how people categorize concepts (Nielsen 1993). Index cards are used to represent different information and participants are asked to organize the pile of cards on a table. Applying this basic method to AUIs, a “sound card sorting task” can be used as a function mapping tool. When researchers have a function set and a corresponding sound set, they can use this method.

Participants are given five to eight sound cards, each containing an experimental sound stimulus. Corresponding five to eight index cards are laid out on the table with a description of the function. Before they start a sorting task, an experimenter explains the meaning of each function to participants and then, they listen to all the sound recordings. Participants pair each sound stimulus with the function which the sound best relates to. They are allowed to have as much time as they want to complete the sorting task. Upon completion, responses are recorded by the experimenter. Then, participants are asked to explain the strategy or rationale they used to pair each sound stimulus and function.

From this task, researchers can get an overall percentage of correct answers for each function. In Table 3, the leftmost column has names of the functions. Each number is stimulus number and bold numbers represent the corresponding (correct) sound for the designated function. Researchers can also obtain a “confusion matrix” (see Table 4). Columns are selected sounds and rows are intended functions. Based on this matrix, researchers can analyze where the participants feel confused (bold numbers) and improve their design in terms of distinguishability. Finally, researchers can analyze participants’ rationale (users’ mental model) of their sorting strategy and compare those opinions with a designer’s intention (designer’s conceptual model).

Here is an example of the report: “Although some participants had more reasoning behind their sound-function pairings than others, most of their explanations were similar to the outcome we expected. For instance, when the magnitude change represents going up, the sound should be higher pitch or should sound like it increases in pitch. When the magnitude change represents going down, the pitch should be lower or sound like it decreases in pitch. This is an example of positive and negative polarity, which also accords with participants’ explanations for functions on and off. Consequently, there was some confusion between magnitude change pairs and function pairs.”

Table 3: Plausible Responses from the Sound Card Sorting Task (Bold Is a Correct Mapping)

Functions	Sound Number																	%
Function On	**18**	**18**	11	**18**	**18**	**18**	**18**	21	9	1	9	**18**	23	10	**18**	9	11	**47**
Function Off	**14**	**14**	3	3	**14**	**14**	**14**	**14**	**14**	21	18	**14**	11	1	**14**	**14**	10	**59**
Magnitude Up	10	**11**	21	1	**11**	**11**	**11**	**11**	**11**	18	**11**	10	18	18	**11**	18	18	**47**
Magnitude Down	12	**10**	22	22	**10**	**10**	**10**	18	**10**	14	**10**	11	14	14	**10**	21	14	**41**
Warning	**23**	**23**	**23**	**23**	1	**23**	1	**23**	**23**	**23**	**23**	**23**	9	9	**23**	1	**23**	**71**
Informing	6	**9**	**9**	12	23	23	**9**	**9**	18	**9**	1	**9**	1	23	**9**	23	**9**	**47**

Thanks to the embodiment (sound cards) of the sound, participants can remember sounds more easily and conduct a sorting task more accurately. Researchers and designers can understand participants’ strategies behind their sorting behaviors and test discernability of the similar sounds. However, with this method if one mapping is wrong, another one should be wrong. It may result in a lower accuracy rate overall. Therefore, researchers can choose whether or not to obligate to pair all sounds with only one function depending on purpose.

Table 4: Plausible Confusion Matrix from the Sound Card Sorting Task (Confusing Points Are in Bold)

		Sound Selected					
		Function On	Function Off	Magnitude Up	Magnitude Down	Warning	Informing
Sound Designed	Function On	80%	0%	**20%**	0%	0%	0%
	Function Off	0%	80%	0%	**20%**	0%	0%
	Magnitude Up	**15%**	0%	80%	0%	0%	5%
	Magnitude Down	0%	**30%**	0%	70%	0%	0%
	Warning	3%	7%	0%	0%	75%	**15%**
	Informing	10%	5%	15%	5%	**20%**	45%

Emotion Mapping: Constructing a Perceptual Structure of Emotional Dimensions

Just as AUIs should represent product functionality, AUIs are required to reflect product (or brand) image. To this end, AUI designers create a sound-specific perceptual structure of emotional dimensions in contrast to general taxonomy for emotions (e.g., Ekman 1992; Plutchik 1994). One of the core methodologies used in such research stems from "Kansei Engineering" (Nagamachi 2002), which can be defined as a method for translating feelings and impressions into design parameters. To this end, researchers tend to use affective words as a medium between design elements and emotions about a specific design domain. This emotional mapping can be used when designers want to identify the relationship between sound alternatives and the emotional dimensions (e.g., brand image map).

For this emotion mapping, researchers can use "dissimilarity ratings" or "proximity matrix" between each sound pair (Bonebright and Flowers 2011). The current paper focuses on the use of affective keyword ratings and multi-dimensional scaling (MDS) technique. In either way, it is recommended to integrate different processes and statistical methods (e.g., factor analysis, multi-dimensional scaling, discriminant analysis, etc.) in a consecutive way.

First, adjective keywords to describe the research domain (product characteristics, brand images, design trends, etc.) need to be gathered based on literature review, expert interview, etc.

Then, researchers reduce affective keywords based on user ratings, expert review, etc. Meanwhile, designers select critical variables of sound, such as tempo, timbre, mode/key, genre, etc. within the limitation of hardware and software specifications, and create sound stimuli by manipulating those variables. User ratings can be collected on the appropriateness of all the sounds for each adjective and the MDS is run (see Figure 2). With an emotional map obtained, researchers can conduct the sound positioning task (i.e., having participants listen to sounds and place each sound on the coordinates of the emotional map) and gain an average coordinates for each sound.

Depending on the statistical recommendation (e.g., scree plot), researchers can apply a 1, 2, or 3 dimensional map in the presentation of MDS results (see Figure 3). Based on the coordinates of each sound, the relationship between sounds and emotional dimensions can be identified. Note that the MDS does not provide any 'name' or 'label' for each axis. Researchers need to specify the name depending on the results. For example, researchers have identified 3 dimensions for a simple tone and named them: unpleasant-pleasant, static-active, and simple-complex (Lee, Jeon, and Han 2003), 2 dimensions for contemporary music: unpleasant-pleasant and soft-strong (Jeon et al. 2004), and 2 dimensions for design elements including color, sound, finishing and materials: warm-cool and human centered-techno centered (Jeon et al. 2008).

Here is an example of the report: “As a result of the MDS, a three-dimensional model regarding the relationship between the sounds and the emotional keywords was constructed, which can account for approximately 95% of all the variance with a Stress index .084. We have identified that three dimensions are able to explain a perceptual structure of the sound-emotion relationship. The first dimension is represented as the horizontal axis in Figure 3(a). In the first dimension, there is a tendency that divides the emotional space between pleasant adjectives such as ‘cool’, ‘cheerful’, and ‘lively’ and unpleasant adjectives such as ‘gloomy’, ‘sad’, and ‘dark’ according to the degree of pleasure. Therefore, we named the first dimension ‘pleasant – unpleasant’. The second dimension is represented as the vertical axis in Figure 3(a). Subsequently, the second dimension was called the ‘complex - simple’ dimension because of a division of emotions between complex adjectives such as ‘uneasy’, ‘confused’, and ‘sharp’ and simple adjectives such as ‘comfortable’, ‘calm’, and ‘common’ according to the degree of complexity. Finally, the third dimension is shown as the axis of the ordinate in Figure 3(a). In the third dimension, there is a tendency that divides the emotional space between active adjectives, such as ‘dynamic’, ‘magnificent’, and ‘harsh’ and static adjectives, such as ‘monotonous’, ‘boring’, and ‘fine’ according to the degree of activity. Therefore, we labeled the third dimension ‘active – static’. Further, each relationship on the 2 dimensions is shown respectively in Figure 3(b), (c), and (d).”

Researchers can iteratively update the dimensions with different populations, stimuli, adjective sets, etc. and finally can generalize the emotion dimension to design emotionally optimized AUIs. Around 20 adjectives seem to be adequate for the 2dimensional MDS presentation. If researchers begin with hundreds of adjective keywords, they can reduce the number of adjectives using user ratings and a factor analysis, etc. For more detailed procedure, see (Lee, Jeon, and Han 2003; Jeon et al. 2004; Jeon et al. 2008).

		Sound A	Sound B	Sound C	Sound D	Sound E	Sound F	Sound G	Sound H	Sound I	Sound J
participant 1	Ultra Thin	1	3	2	4	1	6	3	2	7	3
participant 1	Metallic	2	3	1	5	4	6	4	3	4	3
participant 1	Delightful	3	7	6	1	4	3	2	3	2	3
participant 1	Chic	5	6	4	3	3	2	1	5	1	2
participant 1	Mysterious	2	1	1	6	4	1	5	2	5	2
participant 1	Hand-crafted	1	3	2	4	1	6	3	2	7	3
participant 1	Nostalgic	2	3	1	5	4	6	4	3	4	3
participant 1	Gummy	3	7	6	1	4	3	2	3	2	3
participant 1	Atypical	5	6	4	3	3	2	1	5	1	2
participant 1	Rough	2	1	1	6	4	1	5	2	5	2
participant 1	Delicate	1	3	2	4	1	6	3	2	7	3
participant 1	Transparent	2	3	1	5	4	6	4	3	4	3
participant 1	Artificial	3	7	6	1	4	3	2	3	2	3
participant 1	Techno-romantic	5	6	4	3	3	2	1	5	1	2
participant 1	Glittering	2	1	1	6	4	1	5	2	5	2
participant 1	Soft	1	3	2	4	1	6	3	2	7	3
participant 1	Ultra Minimal	2	3	1	5	4	6	4	3	4	3
participant 1	Optimistic	3	7	6	1	4	3	2	3	2	3
participant 1	Geometrical	5	6	4	3	3	2	1	5	1	2
participant 1	Rhythmical	2	1	1	6	4	1	5	2	5	2
participant 1	Fluid	1	3	2	4	1	6	3	2	7	3
participant 1	Prestigious	2	3	1	5	4	6	4	3	4	3
participant 1	Ambiguous	3	7	6	1	4	3	2	3	2	3
participant 1	Energetic	5	6	4	3	3	2	1	5	1	2
participant 1	Futuristic	2	1	1	6	4	1	5	2	5	2
participant 1	Gleaming	1	3	2	4	1	6	3	2	7	3
participant 1	Indistinct	2	3	1	5	4	6	4	3	4	3
participant 1	High-Glossy	3	7	6	1	4	3	2	3	2	3
participant 1	Embossed	5	6	4	3	3	2	1	5	1	2
participant 1	Semitransparent	2	1	1	6	4	1	5	2	5	2
participant 1	Reflective	1	3	2	4	1	6	3	2	7	3
participant 1	Faded	2	3	1	5	4	6	4	3	4	3
participant 2	Ultra Thin	3	7	6	1	4	3	2	3	2	3
participant 2	Metallic	5	6	4	3	3	2	1	5	1	2
participant 2	Delightful	2	1	1	6	4	1	5	2	5	2
participant 2	Chic	1	3	2	4	1	6	3	2	7	3

Figure 2: Plausible Likert Scale Rating Result

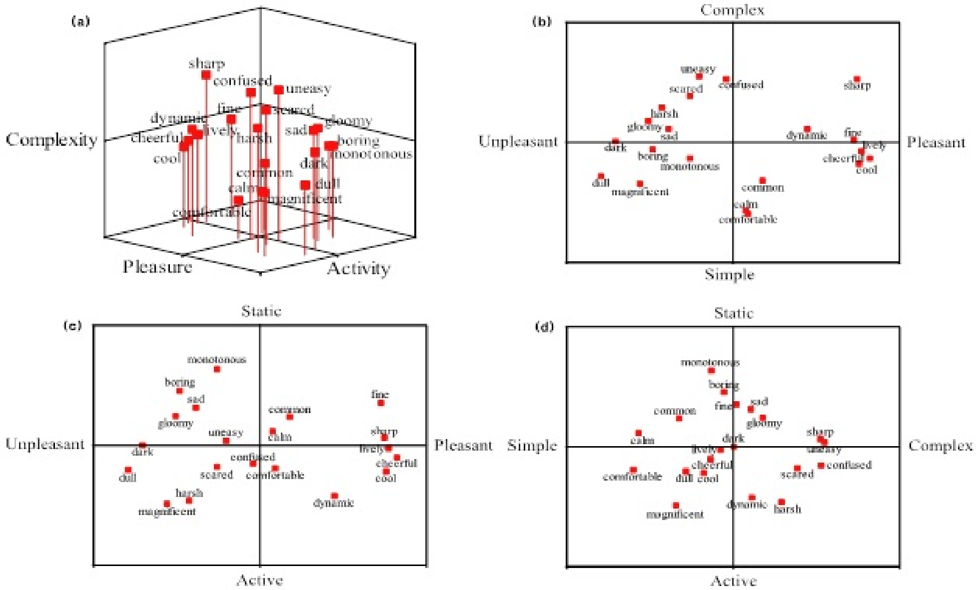

Figure 3: Results Showing (a) Three sound-affect Dimensions, (b) Pleasure & Complexity Dimensions, (c) Pleasure & Activity Dimensions, and (d) Complexity & Activity Dimensions, Respectively
Source: Lee et al., 2003

Design Processes: Industry Case Studies

The previous section introduces instantly applicable methods to AUI evaluation, whereas the present section provides the details of AUI projects composed of multi-phases and methods, aiming at more comprehensive understanding of AUI design processes.

Case Study A: AUI Design Guidelines for Home Appliances

The goal of this project was to develop AUI design guidelines and actual design samples according to product groups of home appliances so that AUIs could be intuitively mapped to designated functions and brand images. Arbitrarily designed (or implemented by engineers) previous auditory signals did not match with users' mental model and their expectancy. Additionally, previous AUI designs were inconsistent within and between product groups, and thus, resulted in user annoyance. Based on this background, this project attempted to provide users with enriched multimodal user experiences and overcome the GUI-centered interface design with systematically designed AUIs. The initial specification of this project was limited to a buzzer. The overall procedure below consists of common elements appeared among several similar projects.

Overall Procedure

1. Gather general AUI guidelines from literature.
2. Analyze AUI needs based on use scenarios.
3. Conduct focus group interviews and a survey on the experience of AUIs with home appliances.
4. Conduct a function analysis according to product groups.
5. Analyze parameters of sounds and create experimental sound pools.
6. Conduct cognitive and affective mappings of AUIs.

7. Create a draft guideline based on the results of empirical studies.
8. Develop professional sound samples mapped onto the guideline.
9. Evaluate final AUI sets on the system architecture (with a prototype or actual product)
10. Develop a final guideline.

Details and Implications

In the first step, we investigated literature and gained general information and guidelines on the use of sounds (limited to non-speech sounds, but beyond the specific application for home appliances), so that we could use them as a baseline to enhance performance and satisfaction of AUIs. In the next step, we created plausible usage scenarios of home appliances. From those scenarios (e.g., “a student wants to raise the temperature quickly with an air conditioner on a hot day”, “a house wife is vacuuming while waiting for completion of washing machine.”), we identified particular situations that require auditory interactions and users’ mental model at that moment.

Additionally, we listened to end users’ (3-4 sessions with 4-5 participants in each group, which made up 15-20 participants in total) opinions about the current status of the AUIs in their home appliances using Focus Groups (FGs) and a simple survey. Participants provided us with what is preferred and what is needed to improve when using those products with AUIs in their everyday lives. As a result of FGs, we found that users considered washing machines and microwaves as the most critical products in terms of the use of sounds.

Meanwhile, we also analyzed functions of home appliances, including refrigerators, air conditioners, washing machines, dish washers, and microwaves. A function analysis (Wickens, Gordon, and Liu 1998) provided us with a very useful taxonomy for application of AUIs. Because the application of different sounds for every function might cause auditory pollution, we categorized the functions as meta-function groups for the application of minimal sounds (Table 5).

Then, we selected several sound profiles within the specification of the buzzers for the products. As a result, number of notes, frequency and frequency range, melody pattern (including polarity), duration of the entire sound, and tempo of the sound were considered. Timbre, which is a critical factor in mapping data to sounds (Walker and Kramer 2004), was excluded because the study was limited to the buzzer specification, which can generate only the single timbre. Based on expert consultation and literature analysis, around 50 experimental sounds were finally created for the experiment.

Sound parameters of these samples were mapped onto the functional hierarchy within the product. It is similar to the application of earcons for hierarchical menus (e.g., Brewster, Wright, and Edwards 1992; Brewster, Raty, and Kortekangas 1996; Brewster 1998; Leplâtre and Brewster 2000) except that sounds were mapped onto the functional hierarchy, instead of the menu hierarchy.

To match sounds with functions, participants rated the appropriateness of every single sound with each function. The results indicated that the auditory signals devised as the specific functions were rated high for the intended functions. This demonstrated that the rules which sound designers applied for the sound samples were corresponding to users’ mental model and expectancy for AUIs of home appliances.

In addition to this direct function mapping, we tried to match sounds with functions using affective words as a medium between them. The results were also promising. For example, the function, ‘Power on’ was linked with the words, ‘alive’ and ‘vivid’, and increasing sounds. ‘Error’ was correlated with ‘embarrassed’ and ‘nervous’, and repetitive sound patterns.

Table 5: Functional Grouping of Home Appliances for AUI

Meta-Functions	Descriptions	Examples
Power on/off	Turn on/off the products	Most of the electronic products
Horizontal shift	Change the mode between the same levels	Select the type of food in the microwave
Vertical shift	Change the magnitude up and down	Decrease temperature in the air conditioner
Function on/off	Start/pause the general functions	Start the washing machine after the option settings
Inform	Inform the end of the function /ask a user's action	Finish the washing cycle/ microwave
Warn	Warn the system's or user's errors	Door is open in the refrigerator
Special functions	Play/(pause) the special functions	Brand-specific wind in the air conditioner

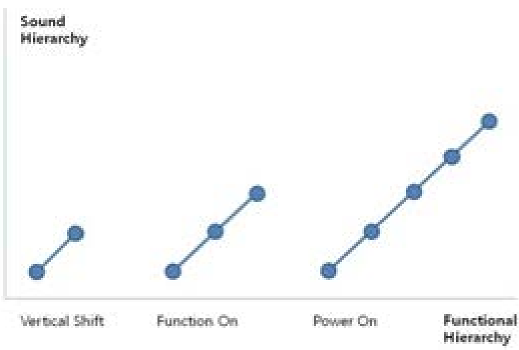

Figure 4: A conceptual figure of sound hierarchy mapped to functional hierarchy. Multiple sound attributes were differentiated due to functional hierarchy including the number of notes, duration, and the range of frequency

To compare newer AUI designs with the existing ones in the usage context, participants evaluated two sets (new and old) of AUI designs on the information architecture of the software-based prototype (e.g., PowerPoint, Flash, or Java). In some cases, we prepared multiple sets (e.g., competitors' products) of AUI designs and evaluated them with the actual products. The new AUI designs obtained significantly higher scores on the appropriateness, preference, and overall satisfaction scales.

Finally, professional sound designers created several sound sets fitting for the detailed guidelines, the brand identity of the company, and each product group image. This project provided a meta-guideline for the AUI design of home appliances. The process consisted of several aspects of interaction design with the target users' iterative evaluations. Nonetheless, it can still be improved. Because the products were just buzzer applications, we excluded crucial sound parameters, such as timbre, loudness, and harmony of the sounds, which we can implement with other devices (e.g., mobile devices).

There are some general considerations when designing AUIs for home appliances. For example, to decide a frequency range AUI designers need to take into consideration masking, buzzers' prominent frequency, older adults' less sensitivity to high frequency, etc. Further, a buzzer-generated frequency is sometimes not the same as a musical frequency (e.g., 1045Hz vs. 1046.5Hz for C6). Thus, AUI designers should always tune in the real product. Looping (repetition) of the sounds is also need to be considered. Generally, we use sounds shorter than 2 seconds in electronic products even though the duration of the sound depends on the type of function.

Case Study B: Emotional Palette of Design Elements

Whereas the previous AUI project focuses on the functional mapping of sounds, this project concentrates more on the emotional mapping of sounds. The Emotional Palette Project uses a systematic approach to the integration of emotional user experience elements in the product design. The goal of the project was 1) to make a common design identity (or language) to foster communications among designers and with outside partners, and 2) to make guidelines for optimized combinations of emotional design elements. Each designer has their own feelings and standards about design elements. To illustrate, a designer may choose a ‘red’ color to express ‘energetic’, whereas another designer may choose ‘black’ to represent ‘energetic’. Even if they all would use ‘red’, each ‘red’ might be differently imagined and expressed (Think about ‘qualia’, one of the important issues of Cognitive Science, see Harman 1998). This variance is good for creativity of the work, but sometimes hinders the desirable congruency to represent corporate identity. There have been several studies about design elements and emotional factors (Brown and Kaye 2007; Lee et al. 2004; Payling, Mills, and Howle 2007; Bresin 2005), but none of them is comparable with this study in terms of the scale or the methodology.

Overall Process

1. Extract affective keywords through various document analysis and trend analysis.
2. Create user experience element stimuli sets (each set of color, material & finishing, and sound).
3. Measure ‘appropriateness’ of stimuli sets for various product groups’ image and user preference.
4. Construct respective emotional dimensions of each product group that contains mappings between keywords and design elements according to user segmentation.
5. Develop a prototype system based on the results of the research above.

Details and Implications

First, 120 affective design keywords were extracted through trend analysis by an expert group (e.g., Nelly Rodi in France). Additionally, we collected 342 trend adjectives by means of literature analysis, and designers’ free association reports. Then, user experience designers—two color experts, two material & finishing experts, and two sound experts—extracted 50 keywords by rating the validity of collected affective adjectives. The standards for the validity were the degree of reflection of the design trend and the appropriateness for each design element. We finally selected 31 design trend keywords (Figure 5), by eliminating overlapped descriptions or technical words.

Each expert group designed stimuli for the 31 affective words. Color was shown as color bars. Material & finishing was displayed as representative pictures. Sound was played as wave files. A few stimuli sets were chosen and elaborated by these experts before the experiment. For the mapping experiment between design elements and keywords, a total of 320 participants were recruited according to each of product group’s market segmentation. Participants were provided with sets of design elements, and asked to answer several questions about preference and fit for participants’ self-image and for each product group’s image. Regarding sound, they could listen to one stimulus repeatedly as much as they want. As a result of the experiment, we obtained a mapping between each design stimulus, affective keyword, and user segmentation, using a multi-dimensional scaling and a correspondence analysis.

Based on the results above, a prototype system was developed to guide designers to properly select and combine emotional elements with their design concepts (see Figure 5). Above all, designers can see 31 adjectives on the 2-dimensional coordinate system. When a designer chooses a trend keyword, the proper color bar and the material & finishing pictures are recommended on the right side of the system. Two or three sounds that were rated highly for that trend keyword can be heard via sound tabs. Moreover, designers can check the preference of design elements according to the user segmentation on the bottom right. Finally, diverse combinations of all of these elements can be presented at once. Note that these design elements were intended to serve as 'examples' to construct a common language among hundreds of designers for corporate design identity, not necessarily to be used for real products.

Figure 5: A screen shot of the emotional palette prototype system for mobile devices. Design elements mapped onto keywords and segmented user groups

Conclusions

This paper presented practical evaluation methods and design processes of the AUI design, which is in line with traditional "design through research". Recently, interests in "research through design" have also increased (e.g., Gaver 2012; Zimmerman, Forlizzi, and Evenson 2007). In either case, it commonly requires a designer to be both a practitioner and a scientist. Moreover, it calls for "participatory design", which means that designers should involve users as design participants to reflect their mental model on the design, and thus, users can use the product more intuitively.

Since Pythagoras and Plato, there have been attempts to determine an appropriate relationship between the physical phenomena of sound and psychological responses to them. Along the same line, a semiotic approach to today's sound design (Pirhonen et al. 2007) looks valid because it is the science of mapping between auditory signals and their meanings (e.g., function, hierarchy, brand image, or emotions, etc.). Given that individual responses to sound heavily depend on one's emotional states or other contextual situations, to conduct more scientific research, we have adopted language (e.g., functional or affective words) as a medium between sound and mind. Obviously, most people have expertise in their own language and use it as an effective communication tool in everyday lives.

The methods and processes delineated in the current paper are not exhaustive or mutually exclusive. Certainly, they are not all of what is currently used and the guidelines presented here might not work for some of other contexts. An auditory display community (e.g., ICAD, International Community on Auditory Display) has yet developed the standard sounds, methods, tools, or evaluation techniques of AUI design. Researchers are well aware that AUI design is a truly interdisciplinary domain and has moved from "art and science" into "art with science". This paper is expected to contribute to laying a brick for that foundation. Implementing AUIs is deeply related to product design or hardware design (e.g., requiring additional board, speakers, and amps). Therefore, understanding AUI design will also be helpful for other design areas. I hope that various designers and researchers can adopt and expand methods and approaches described here and apply the overall process to their own design works. "

REFERENCES

Andersen, T. H., and S. Zhai. 2010. "'Writing with music': Exploring the use of auditory feedback in gesture interfaces." *ACM Transactions on Applied Perception* 7 (3): 17:1-24.

Blattner, M. M, D. A. Sumikawa, and R. M. Greenberg. 1989. "Earcons and icons: Their structure and common design principles." *Human-Computer Interaction* 4: 11-44.

Bonebright, T. L., and J. H. Flowers. 2011. In *The Sonification Handbook*, edited by T. Hermann, A. Hunt, J. G. Neuhoff, 111-144. Berlin: Logos Verlag.

Bresin, R. 2005. "What is the color of that music performance." Paper presented at International Computer Music Conference (ICMC2005), Barcelona, Spain, 2005. 367-370.

Brewster, S. A. 2002. "Overcoming the lack of screen space on mobile computers." *Personal and Ubiquitous Computing* 6 (3):188-205.

———. 2008. "Chapter13: Nonspeech auditory output." In *The human computer interaction handbook*, edited by S. A and J. J. New York: Lawrence Erlbaum Associates.

———. 1997. "Using non-speech sound to overcome information overload." *Displays* 17: 179-189.

———. 1998. "Using Non-speech sounds to provide navigation cues." *ACM Transactions on Computer-Human Interaction* 5 (3): 224-259.

Brewster, S. A., P. C. Wright, and A. D. N. Edwards. 1992. "A detailed investigation into the effectiveness of earcons." Paper presented at First International Conference on Auditory Display, Santa Fe, USA, 1992. 471-478.

Brewster, S. A., V. P. Raty, and A Kortekangas. 1996. "Earcons as a method of providing navigational cues in a menu hierarchy." In *HCI'96*.

Brown, L. M., and J. J. Kaye. 2007. "Eggs-ploring the influence of material properties on haptic experience." Presented at Second International Workshop on Haptic and Audio Interaction Design, Seoul, Korea. 1-2.

Edwards, A. D. N. 1989. "Soundtrack: An auditory interface for blind users." *Human-Computer Interaction* 4: 45-66.

Edworthy, J. 1998. "Does sound help us to work better with machines? A commentary on Rauterberg's paper 'About the importance of auditory alarms during the operation of a plant simulator'." *Interactive with Computers* 10: 401-409.

Ekman, P. 1992. "An argument for basic emotions." *Cognition and Emotion* 6: 169-200.

Faste, T., and H. Faste. 2012. Demystifying "design research": design is not research, research is design, IDSA.

Gaver, W. W. 1986. "Auditory icons: Using sound in computer interfaces." *Human-Computer Interaction* 2: 167-177.

———. 2012. "What should we expect from research through design?" Presented at Conference on Human Factors in Computing Systems (CHI'12), Austin, Texas, USA.

Glinert, E. P., and B. W. York. 2008. "Computers and people with disabilities." *ACM Transactions on Accessible Computing* 1 (2): 1-7.

Harman, G., ed. 1998. "Some philosophical issues in Cognitive Science: Qualia, intentionality, and the mind-body problem.". In *Foundations of Cognitive Science*, edited by M. I. Posner, 831-948. Boston, MIT Press.

Helle, S., G. Leplâtre, J. Marila, and P. Laine. 2001. "Menu sonification in a mobile phone -- a prototype study." Paper presented at *Seventh International Conference on Auditory Display*. Espoo, Finland.

Hermann, T. 2008. "Taxonomy and definitions for sonification and auditory display." Paper presented at 14th Internatinal Conference on Auditory Display (ICAD2008), Paris, France.

Jeon, M., and B. N. Walker. 2009. "'Spindex': Accelerated initial speech sounds improve navigation performance in auditory menus." Paper presented at *Human Factors and Ergonomics Society (HFES 2009)*, San Antonio, TX.

Jeon, M., B. K. Davison, M. A. Nees, J. Wilson, and B. N. Walker. 2009. "Enhanced auditory menu cues improve dual task performance and are preferred with in-vehicle technologies." Paper presented at *The First International Conference on Automotive User Interfaces and Interactive Vehicular Application*, Essen, Germany.

Jeon, M., U. Heo, J. H. Ahn, and J. Kim. 2008. "Emotional palette: Affective user experience elements for product design according to user segmentation." Paper presented at *Sixth International Conference of Cognitive Science*, at Seoul, Korea.

Jeon, M., J. H. Lee, Y. E. Kim, and K. H. Han. 2004. "Analysis of musical features and affective words for affection-based music search system." Paper presented at *Korean Conference on Cognitive Science*, at Seoul, Korea.

Jeon, M., B. N. Walker, and A. Srivastava. 2012. "'Spindex' (speech index) enhances menu navigation on touch screen devices with tapping, wheeling, and flicking gestures." *ACM Transactions on Computer-Human Interaction (TOCHI)* 19 (2): 14:1-27.

Jeon, M., and B. N. Walker. 2011. "Spindex" (Speech Index) improves acceptance and performance in auditory menu navigation for visually impaired and sighted users. *ACM Transactions on Accessible Computing* 3 (3): 10:1-26.

Juslin, P. N., S. Liljeström, D. Västfjäll, and L-O. Lundqvist, eds. 2010. "How does mkusic evoke emotions? Exploring the underlying mechanisms." In *Handbook of music and emotion,* edited by P. N. Juslin and J. A. Sloboda. Oxford: Oxford University Press.

Juslin, P. N., and D. Västfjäll. 2008. "Emotional responses to music: The need to consider underlying mechanisms." *Behavioral and Brain Sciences* 31: 559-621.

Kenealy, P. 1988. "Validation of a music mood induction procedure: Some preliminary findings." *Cognition and Emotion* 2: 41-48.

Kramer, G. 1994. "An introduction to auditory display." In *Auditory display: Sonificaiton, audification, and auditory interfaces*, edited by G. Kramer. MA: Addison-Wesley.

Lee, J. H., M. Jeon, Y. E. Kim, and K. H. Han. 2004. "The analysis of sound attributes on sensibility dimensions." Paper presented at *The Eighteenth International Congress on Acoustics*, Kyoto, Japan, April 2004.

Lee, J. H., M. Jeon, and K. H. Han. 2003. "The sound sensibility dimension for auditory displays." Paper presented at *The 2003 International Conference on Cognitive Science*, Sidney, Australia. July 2003.

Leplâtre, G., and S. A. Brewster. 2000. "Designing non-speech sounds to support navigation in mobile phone menus." Paper presented at *The 6th International Conference on Auditory Display*, Atlanta, GA.

Marila, J. 2002. "Experimental comparison of complex and simple sounds in menu and hierarchy sonification." Paper presented at *The Eighth International Conference on Auditory Display*, Kyoto, Japan.

Mayer, J. D., J. P. Allen, and K. Beauregard. 1995. "Mood inductions for four specific moods: A procedure employing guided imagery vignettes with music." *Journal of Mental Imagery* 19: 133-150.

McGookin, D, S. A. Brewster, and W. Jiang. 2008. "Investigating touchscreen accessibility for people with visual impairments." In *NordiCHI 2008*. Lund, Sweden: ACM Press.

Nagamachi, M. 2002. "Kansei Engineering as a powerful consumer-oriented technology for product development." *Applied Ergonomics* 33: 289-294.

Nees, M. A., and B. N. Walker, eds. 2009. "Auditory interfaces and sonification." In *The Universal Access Handbook,* edited by C. Stephanidis. New York: Lawrence Erlbaum Associates.

Nielsen, J. 1993. *Usability engineering*. Boston: AP Professional.

Norman, D. A. 2004. *Emotional design*. New York: Basic Books.

———. 2007. *The design of future things*. New York: Basic Books.

Palladino, D., and B. N. Walker. 2008. "Navigation efficiency of two dimensional auditory menus using spearcon enhancements." Paper presented at *Annual Meeting of the Human Factors and Ergonomics Society (HFES 2008)*, New York, New York, September 22-26.

Panksepp, J., and G. Bernatzky. 2002. "Emotional sounds and the brain: The neuro-affective foundations of musical appreciation." *Behavioural Processes* 60: 133-155.

Payling, D., S. Mills, and T. Howle. 2007. "Hue music-creating timbral soundscapes from coloured pictures." Paper presented at *International Conference on Auditory Display,* Quebec, Canada, 2007. 91-97.

Peres, S. C., V. Best, D. Brock, B. Shinn-Cunningham, C. Frauenberger, T. Hermann, J. G. Neuhoff, L. V. Nickerson, and T. Stockman. 2008. "Auditory interfaces." In *HCI beyound the GUI: Design for haptic, speech, olfactory, and other nontraditional interfaces*, edited by P. Kortum, 147-196. Amsterdam: Morgan Kaufmann.

Pirhonen, A., K. Tuuri, Mustonen M., et al. 2007. "Beyond clicks and beeps: In pursuit of an effective sound design methodology." In *HAID 2007,* edited by I. Oakley and S. A. Brewster**,** LNCS 4813. 133-144.

Plutchik, R. 1994. *The psychology and biology of emotion*. New York: Harper Collins Coll.

Stratton, V. N., and A. H. Zalanowski. 1991. "The effects of music and cognition on mood." *Psychology of Music* 19:121-127.

T., Hermann, Hunt A., and J. G. Neuhoff. 2011. *The sonification handbook*. Edited by A. Hunt., T. Hermann and J. G. Neuhoff, Berlin, Germany: Logos Verlag.

Walker, B. N., and G. Kramer. 2004. "Ecological psychoacoustics and auditory displays: Hearing, grouping, and meaning making." Edited by J. Neuhoff, *Ecological psychoacoustics*. New York: Academic Press.

———. 2006. "Auditory displays, alarms, and auditory interfaces." In *International Encyclopedia of Ergonomics and Human Factors 2nd Edition*, edited by W. Karwowsky, 1021-1025. New York: CRC Press.

Walker, B. N., J. Lindsay, A. Nance, Y. Nakano, D. K. Palladino, T. Dingler, and M. Jeon. 2013. "Spearcons (Speech-based earcons) improve navigation performance in advanced auditory menus." *Human Factors* 55 (1): 157-182.

Wickens, C. D., S. E. Gordon, and Y. Liu. 1998. *An introduction to human factors engineering* New York: Addision Wesley Longman.

Yalla, P., and B. N Walker. 2007. Advanced auditory menus Atlanta: Georgia Institute of Tehcnology GVU Center.

Zimmerman, J., J. Forlizzi, and S. Evenson. 2007. "Research through design as a method for interaction design research in HCI." Paper presented at *Conference on Human Factors in Computing Systems (CHI'07),* San Jose, CA, USA.

ABOUT THE AUTHOR

Dr. Myounghoon Jeon: Assistant Professor, Department of Cognitive and Learning Sciences/Department of Computer Science, Michigan Technological University, Houghton, Michigan, USA

The International Journal of Design in Society is one of six thematically focused journals in the collection of journals that support the Design Principles and Practices knowledge community—its journals, book series, conference and online community.

The journal interrogates the social sources of design, and the social effects of design. Focal points of interest include design policy, the human impacts of design, design values and design as business.

As well as papers of a traditional scholarly type, this journal invites case studies that take the form of presentations of practice—including documentation of socially-engaged design practices and exegeses analyzing the effects of those practices.

The International Journal of Design in Society is a peer-reviewed scholarly journal.

ISSN 2325-1328

ISBN 000-0-00000-000-0