SUBJECTIVE EXPERIENCE METHODS FOR EARLY CONCEPTUAL DESIGN OF AUDITORY DISPLAYS

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ABSTRACT

We review a cross-section of subjective experience methods focused on the early conceptual design of auditory displays. The motivation of this review is to support expert and novice designers in creating auditory displays in human-computer interaction by introducing them to these methods. A range of available guidance and current practice is firstly analysed. Subsequently, the key methods and their concepts are discussed with examples from existing studies. A complementary framework is presented to highlight how these methods can be used together by auditory display designer at the early conceptual design stage. The results from these studies help to demonstrate the need for a greater awareness and use of this type of method in early conceptual design to uncover pragmatic mental models and associated salient cognitive attributes. The attributes can be related to subjective judgements such as quality, preference, or context among many. This type of approach differs from many quantitative approaches which are strictly focused on the usage aspects of auditory displays. The manner of quantitative approaches is to use hypothesis and validation criteria, however these cannot deal in a structured way with ephemeral judgements such as emotion, mood, or with subject dependant information such as tacit knowledge. The increasing use of interactive auditory displays is one area where this type of early conceptual design method can help in ensuring the designed interaction and the concrete mapping it uses reflects the considered behaviour of potential users including aspects of the inner needs, desires, and tacit knowledge. This approach will help in considering the emotional, intellectual, and sensual aspects of interactions when designing auditory displays. We close by reflecting on the results and discussing future lines of research using these methods.

1 Introduction

The focus of this paper is on the various subjective experience methods available for use. These qualitative methods gather and analysis the user's cognition of sound, subjective experiences, and pragmatic mental models[1] to obtain a deeper and more detailed understanding of their requirements than can be obtained with most objective (quantitative) methods. Gathering and analysing this type of tacit information and experience is difficult. In the case of experience, it cannot be objectively measured as a particular experience will never be exactly the same for any two individuals. Tacit knowledge, inner needs, and desires of people are useful inputs to a design process as they increase the results quality and the percentage of design relevant information. These types of subjective early explorations when combined with methods such as interviews or questionnaires produce more reliable information. This type of knowledge has yet to be systematically included in the growing knowledge of auditory display display and the wider field of sonic interaction design although the work in the SMC[2] and the COST SID[3] research networks has begun to address this issue. Subjective experience methods can bridge between the user and the designer allowing the designer to gain insights into the rich relationships between listeners' and their soundscapes. An understanding of these relationships can help designers think more creatively about new design possibilities. This may help answer the question of Hug [1] who argued that there is comparatively little knowledge about how to inform the sonic design of ubiquitous technology and situations, in particular how a specific meaning in a specific context is conveyed whilst forming an aesthetic unity between the operation and the object/s involved. Previous sound quality studies [2, 3] have focused on related issues. Blauert noted that "*to be able to design other than intuitively, data should be made available to the engineer which tell him which meanings subjects tend to assign to specific sound and what the judgement on the desirability will possibly be*" [4]. The cross-section of methods provided by this review can help provide this data to the designer.

The majority of usability studies conducted in auditory display takes a scientific approach or methodology. These focus on the observation of users and their behaviours, in particular on what is said and on what is done by users. An example of a quantitative method would be Fitts' law for measuring human movement as a means to predict the time required to rapidly move to a target area in an interface [5]. The recordings and analysis from these studies are used to explore people's habits, choices and abilities as they relate to the auditory display. Observation and inference captures the invariant features of behaviour rather than what was unique in it. This does not explore the inner thoughts or feelings of people, yet these are important as these subjective phenomena contribute to how people experience. This type of inner view of people can help in balancing the objective observations by providing this type of useful but alternative design information. An example of this inner view is shown by the '*say – do – make*' model [6]. It breaks the comprehension of user experience into understanding of the verbal (what people know and tell, '*Say*'), of behaviours (what people see and observing what they do, '*Do*'), and of tacit & latent information (the non-verbal means used by people to describe and represent experience, '*Make*'). This model integrates two types of information, the first is inspirational which is focused on qualitative data such as concerns/values, metaphors or mappings. The second type is informational, which is focused on quantitative information such as direct measures (i.e. rankings from Likert scales) or calculated measures such as those calculated using statistical techniques.

The advice of Koskinen [7] for this type of approach is to se-

[1] In the case of this article, we refer to *pragmatic mental models* as those people use and form while interacting with an environment.

[2] http://www.smcnetwork.org/

[3] http://www.cost-sid.org/

lect primary, secondary, and deviant user groups who represent the spectrum of potential users ranging from experts to possible future users to those with extreme or unusual needs. Working with these different groups helps provide inspirational design information and to test the designer's hypotheses about the target groups. The next stage uses this information to make systematic inferences to help understand the user. Systematic inference or analytic induction [8] is where hypotheses are progressively refined from the data and tested with the data until they describe it thoroughly. This approach helps designers select the most appropriate concepts and designs.

A common feature of subjective techniques is that participants provide feedback without explicit direction from the designer / experimenter. This helps prevent any designer biases from influencing the participants. The results of this approach are diverse and allow both communal and individual meaning to be ascribed to the sounds by the participants. The techniques covered in this review are limited to individual focused rather than group focused techniques. Time is a practical consideration for many designers and individual techniques are much less time consuming than most group oriented approaches [9]. These individual techniques can potentially help in avoiding group situations where there is a possibility of diminished creativity [10]. They can be combined with group oriented techniques such rich user cases [11] or the descriptive analysis process [9].

A selection of the available techniques are explored in this paper and include repertory grids [12, 13], similarity ratings/scaling [14, 15], sonic maps & '*ear-witness accounts*' [16], '*earbenders*' [17], and the context to basic design approach [18]. This selection provides exemplars that highlight the range of subjective techniques. Designers who uses these techniques at the early stages of auditory display development will improve the quality and the relevance of design information available to them when compared other techniques such as questionnaires. This can help in avoiding any mismatch between the auditory design specifications (i.e. what the designers intended for the listeners' to hear) and the actuality of what the users hear. The conceptual stage design choices are those which have the greatest impact on these types of mismatch. There is no one size fits all technique or approach that can address all the issues or insights raised. The only approach to successfully gather all the necessary information is to a range of complementary techniques. Examples of how these techniques can complement each other will be highlighted in this review. The design framework provides a structured approach for designers who wish to use this range of complementary techniques.

2 Current Practise and Guidance

There is a growing acknowledgement of the need for techniques and practises to provide subjective experience information. These new techniques need to present their results in an appropriate manner for designers. This type of technique varies in perspective as some take the view of the users (user-centered), others explore the experience in relation to the product or interface (product-centered), and a final group focuses on the interaction between the user and the product (interaction-centered). Product-centered design guidelines for understanding and using experiences are available for product development [19] and for assessing the quality of experience of a product during its concept, planning, and use [20]. User-centered categories "*think, do, use*" [21] guidelines reflecting Sander's idea [6] of "*say, do, make*" as well as design guidance for targeting motivations, actions, and contexts [22] are available. There are several interaction-centered models for guidance including Wright's [23] four threads of compositional, sensory, emotional and spatio-temporal, Pine's et al.'s model [24] and Overbeeke's [25] model of experiences concentrating on the aesthetics of interaction with interface and action coupled into time, location, direction, modality, dynamics and expression relationships. The starting point for all of these guidelines requires that designers learn about basic interactions and experiences for the interface, scalability and unfolding of the experience.

3 Subjective Experience Methods

Subjective experience methods are useful in providing a different viewpoint to more performance based objective paradigm methods, which have been typically used for gathering design relevant information about auditory displays. This perspective explores user's needs, desires, mental models, and tacit knowledge. It provides a different type of information than returned from quantitative analysis of auditory display use. User experience is one aspect of subject experience information and it requires the psychological relationship between the users and the sounds used by the auditory display be analysed. This can help in preventing the common problem of ad-hoc selections of sounds for an auditory display [26, 27]. These methods contribute to extending existing practise by providing richer insights into how sound creates and influences the relationship between the user and context of the auditory display. This approach helps in estimating the diversity in users [28] and can better connect with all the potential target users [29] of a product. Audio and its interpretation is a relatively unexplored field with regard to how a listener construes their own experiences. These methods provide a valid approach when designers are looking for information concerning the attributes listeners' associate with particular sounds. The difference between scientific approaches and design approaches are that scientists aim to understand explicitly with a thorough explanation while designers seek an implicit understanding in order to design.

The methods covered in the following paragraphs offer a range of unique and complementary viewpoints on subjective experience. The repertory grid has been described as a means to "*build up mental maps of the clients world in their own words*" [30], similarity scaling provides a means of exploring the perceptual or attribute space for a set of stimuli, while sonic mapping documents the critical sounds and summarises the salient features of an acoustic environment. Earbenders classify narratives into task, information, and data categories to provide inspirational for new designs. Context to basic design uses creative design practises to explore contextual factors to find the important subjective aspects for the development of computational artefacts which link physical action to sonic feedback. Each of these methods provides a part of the wider picture, combining a number of them result in a better understanding for the auditory display design. Future work in this area will combine the objective observation of typical usability studies and subjective experience techniques to explore the use of this approach in design auditory displays. After reviewing this range of techniques, we suggest a design framework which incorporates these methods that was developed from our sonic interaction design processes and design experiences.

3.1 Repertory Grid

The repertory grid [12, 13] is based on Kelly's view where the world is seen through similarities and contrasts of situations and events. The approach uses direct elicitation, asking the individual participants to use their own words to describe the events. This approach does not require extensive prior training for subjects or a lengthy group discussion to create a vocabulary for the set of sounds. Direct elicitation is based on the argument that there is a link between a sensation and the verbal arguments used by a person to describe the sensation. This method extracts the listeners' criteria underlying their judgements about a set of sounds as it allows a listener to use their own words and language to judge the sounds, in a fashion that ensures the construct labels are meaningful to them. The language used by listeners' will be varied and at times vague, however, the relationships found have the potential to supply meaningful information about the entire set of sounds and their interrelationships. Interpreting this kind of verbalisation requires classifiers / sorters to codified the participants responses [31, 32]. This type of interpretation found large degrees of dissimilarity between classifiers but only for a very small number of the sounds. The information produced from this method can provide various types of results as shown in Figure 1. It has been used to explore multichannel and spatial audio subjective experiences of loudspeakers [33, 34].

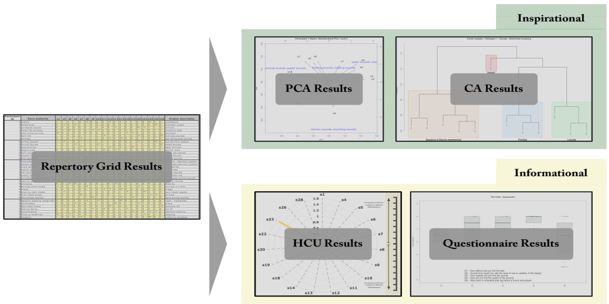

Figure 1: *The repertory grid [12, 13] provides both inspirational and informational results which are useful for early design stages.*

Advantages Little or no training required, individual unbiased responses, statistical methods can be used to provide perceptual projection mappings, and the descriptors can be combined with other textual interpretative methods such causal uncertainty [35].

Disadvantages Individual rather than group / consensus language and specifics, however the statistical visualisations may be difficult to interpretation. Linguistic or semantic knowledge needed to interpret responses.

3.2 Similarity Scaling

The similarity scaling technique [36] is a derivative of the similarity ratings technique [37] where sounds are scaled and sorted with regard to acoustic or physical dimensions. It is best suited to similar sounds as it makes an implicit assumption that the sounds only vary on a small number of continuous auditory attributes or dimensions. This approach allows for examining a listener's perceptual structure for a given set of stimuli and a given attribute or dimension. Information of this type is useful for understanding how and why listeners' confuse particular sounds. A difference between this technique and similarity rating is that sounds were not played in pairs but presented on a 2D randomised grid and allows playback of multiple sounds under a cursor as well as the sorting of the sounds. The individual dissimilarity matrix results from this testing are analysed using multidimensional scaling to produce the perceptual structure mapping of the sounds to locations in an n-dimensional space. This can be used to create a visual depiction of the perceptual space showing how people relate or cluster the stimuli based on a set of attributes or particular dimensions. It has been used to study the categorisation and perception of environmental sounds [14] and synthesised sounds [36].

Advantages Little or no training required, statistical methods can be used to provide perceptual projection mappings, offers new alternative to similarity ratings approach. This may allow for better retention of sounds and may reduce listener fatigue. Sorting data allows more sounds to be compared than with pairwise comparison test.

Disadvantages Focus is on a small number of attributes and the statistical results may be difficult to interpretation. Sorting data is not well suited to this type of analysis.

3.3 Sonic Maps & Ear-witness Accounts

The idea behind sonic mapping [16] is to help the original auditory environment to be experienced, to identify the key sounds in the environment, and to use 'earwitness' accounts to help summarise this information. The sonic mapping technique consists of analysing the auditory elements of an environment as well as identifying the key sounds and the associated meaning given to them. Sonic mapping uses three categories of background, contextual, and foreground with visible and hidden groupings, further divided into subgroups of emotional, action, and signals for sounds. This technique classified sounds as speech, music, everyday, or abstract/unknown. The earwitness account is a way of collating the sonic mapping information into a narrative form. This helps the design of auditory displays for similar types of sonic environments, as it allows designers identify mismatches between the intended message and how listeners' interpreted it. It has been used to explore narratives with novice auditory display designers as a means to create auditory interfaces suitable for a particular auditory environment [16]. The results from this new technique produce materials for discussion within a participatory design session. These can be used to mediate the discussions by providing artefacts that facilitate common understanding. This technique can be used by an individual or conducted as a group activity.

Advantages Little or no training required, individual unbiased accounts, highlights the salient auditory sounds in a soundscape.

Disadvantages Group consensus through mapping may lose aspects of rich sonic environments. It provides a useful overview of the set of sounds but little design or guidance on how these link to one another or what are the key subjective aspects a listener attaches to the sounds.

3.4 Earbenders

Barrass's [17] idea used short stories to explore people's experiences and the meaning they attribute to sounds as part of their interactions with everyday objects. He collected a database of 150 stories containing semantic, syntactic, and pragmatic relations. A verbal or written account of an activity is collected, its key features are identified and broken down into task, information, and data categories. The results are explored in the database to find similar matches. These matches are provided as a starting point for a new auditory display design. This helps explore the ways in which sounds are organised and how people interpret the sounds. This information shows how and which sounds can be useful in an auditory display. These narratives can help designers to understand the user's experience of their auditory environments. Earbenders explore where sounds might be useful in computational artefacts and provides structured design suggestions. It can be seen as a forerunner to auditory design patterns [38].

Advantages Set of predefined relations immediately available as starting points. Concrete guidelines and aspects of auditory design and mappings are produced.

Disadvantages A good inspirational starting point but does not consider the users or domain unless added to the database. Super-ceded in many aspects by auditory design patterns.

3.5 Context to Basic Design

The context to basic design process [18] is shown in Figure 2. The aim of this technique is to integrate the creative design practises with contextual influences (users, environments, or activities) with situated design practises. This new approach creates artefacts that are both sonically augmented and responsive to physical manipulation, an example of this approach is shown by an augmented coffee maker [39]. The approach links action and everyday sound to provide auditory displays that suggest investigation by a combination of continuous sonic feedback and simple physical actions. This method includes a subjective accounting of the observed sounds where the actionhood of the sounds are analysed using a modified task analysis method [40], in conjunction with a number of specific action related aspects such as general parameters, action descriptors/examples, action label/category, the dynamics of the sound, and a number of acoustic descriptors. These aspects consisted of thirty primitives split into elementary or composite/complex action primitives. These formed a foundation for a future taxonomy of domestic kitchen contexts. The results of this approach highlight new ways of incorporating sonic feedback with physical actions in computational artefacts. One of these results from this approach is a 2D matrix of combinations with action primitives plotted against everyday sound processes, which can be used as inspiration for new interface ideas.

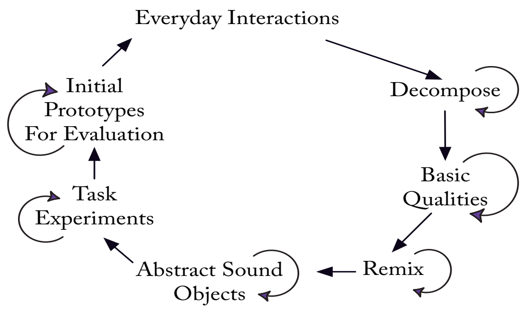

Figure 2: *The context to basic design process [18].*

Advantages Structured process from analysis to prototype creation tailored for the particular context.

Disadvantages Some design knowledge required and may require producing many iterations to focus on a suitable prototype. The re-mixing and morphological design matrix [41] aspects require good design skills to interpret correctly and may be difficult for novices.

4 An Auditory Display Design Framework Incorporating Subjective Experience Methods

The techniques presented in this review focus on subjective experience and meaning with the goal of designing with people rather than for them. They are used to gather and interpret the thoughts of intended users. This approach helps in determining users' needs and desires as well answering questions like what a person thinks of when they hear a sound or what sounds do they find confusing. The advantage of these techniques are that they work with experienced and with naive participants. The techniques can be used in a number of stages of auditory display design. Our work in sonic interaction design lead us to create an auditory display design framework for subjective experience methods. This framework uses the techniques discussed in the review and is shown in Figure 3. It is divided into two stages, *sound creation* and *sound analysis*. This division can be seen as where sounds are selected for a particular auditory display and its context in the first stage, while in the second stage, they are evaluated using a selection of the methods previously presented.

The design framework uses the complementary methods presented in the review to provide a structured approach for auditory display designers to elicit useful design information at the early conceptual stages of design. The first stage is that of sound creation where a real sound is designed or a new sound is created to address the needs of the design. The second stage is where the sound or sounds are analysed to provide verification or more details on the them. The subjective experience methods can be seen as complementary in this type of approach and each adds different yet important aspects to the end results of both the creation and analysis stages. An example is where causal uncertainty measures are used with textual descriptors from sonic mapping or the repertory grid to help designers refine their sound selections by removing confusing sounds.

4.1 A Two Stage Framework Using Subjective Experience Methods for Sound Creation and Sound Analysis

The implicit view we used as for evaluation of the sounds in the early conceptual stages of design is shown in Figure 3. This approach consists of a number of successive steps beginning with a definition of the context and purpose of the auditory display and ending with an actual evaluation of the sounds. The approach is divided into two distinct stages, *sound creation* and *sound analysis*. The approach of this framework is that you complete the first stage before moving to the next stage but that within each stage, you select the mix of methods appropriate to your design needs. Sound creation is focused on defining the auditory display and selecting a set of sounds. The selection of sounds involves using existing sounds or creating new sounds, these may be real, synthetic or a mix of both. Sound analysis is concerned with examining the set of sounds to determine various subjective experience properties and attributes. These examinations use a range of methods, each focused on a particular aspect. The final step of the sound analysis stage is where the results from the various other methods are used to produce a final evaluation on the set of sounds to be used in the auditory display.

The steps for the design framework are numbered in Figure 3 for convenience and this does not indicate a set sequence for method use. The *sound creation* stage will typically follow from steps 1 to 4 in sequence, however this does not have to be the case for the steps within the *sound analysis* stage. In the *sound analysis* stage, anything from a single path to all paths can be select to meet the particular design needs, see the bottom part of Figure 3, can be used to produce the evaluation results.

4.2 Sound Creation:

- *1 - Context and Auditory Display Definition*: The purpose of the auditory display is defined, the context is determined, the initial conceptual design including possible sounds and mappings are created.
- *2 - Selection of Sounds*: A pool of sounds which can fit the selected mappings are gathered and organised for evaluation. These sounds can be real, synthetic or a mix of both.
- *3 - Create the Sounds*: If necessary edit existing or create new sounds. These sounds can be real, synthetic or a mix of both.
- *4 - Listen to the Sounds*: If they do not sound right for the mapping or events, try again with other sounds.

4.3 Sound Analysis:

- *5 - Evaluate Scaling / Mappings of the Sounds*: The subjects listen and compare the sounds and the mappings or

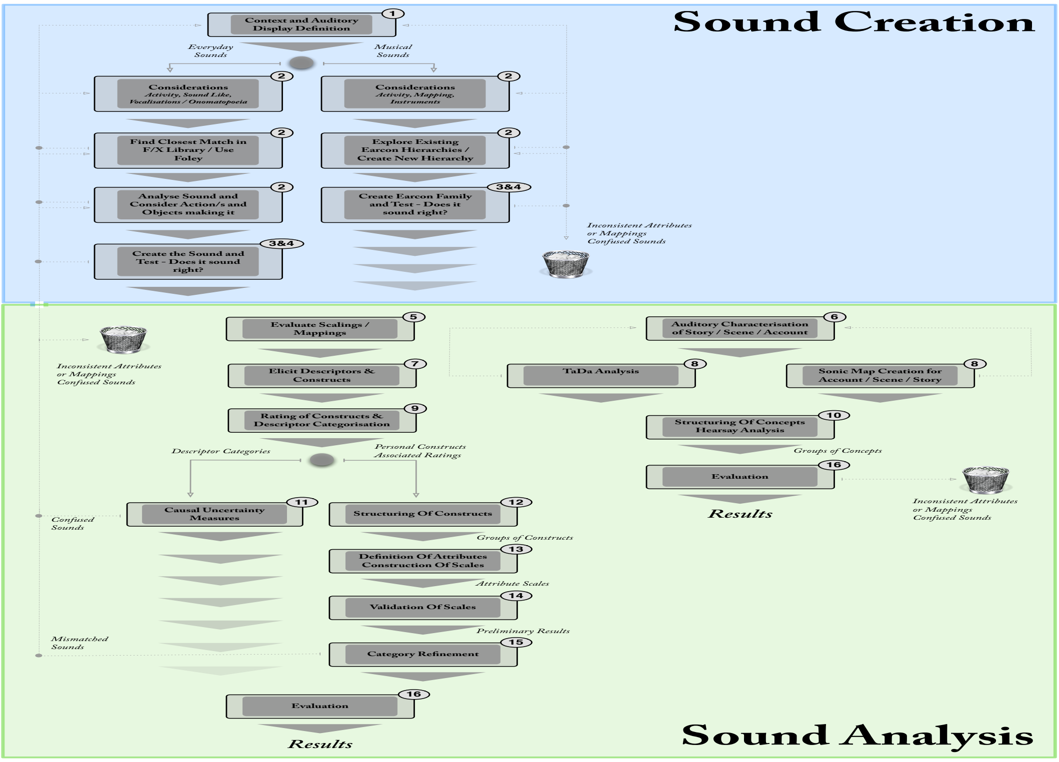

Figure 3: *Two stages in our sonic interaction design process.*

attributes being used.

- *6 - Auditory Characterisation of Story/Scene/Account*: This is where a narrative for the sounds and environment are created.
- *7 - Elicit Descriptors & Constructs*: The participants created textual descriptors for the sounds presented.
- *8 - TaDA & Sonic Mapping*: The narrative / descriptors are analysed and broken down into the different types and aspects of sounds occurring.
- *9 - Rating of Constructs & Descriptor Categorisation*: Each subject rate the stimuli using these constructs created in the last stage.
- *10 - Hearsay Analysis / Structuring*: Take the auditory patterns and key sounds to create a short summary of salient points that could be reused in other auditory display contexts.
- *11 - Causal Uncertainty Measures*: The categorisation details are used to calculate the causal uncertainty of sounds.
- *12 - Structuring of Constructs*: Cluster analysis, multidimensional scaling and principal component analysis of the ratings data are used to clarify the attributes and reduce the dimensionality of the data as well as removing redundancy.
- *13 - Definition of Attributes, Construction of Scales*: The construct groups are analysed for their content. The appropriate descriptions for the participant identified attributes are then formulated. The rating scales are defined from these attributes.
- *14 - Validation of Scales*: The scales created are explored in terms of existing categorisations and taxonomies to test the appropriateness of the scales.
- *15 - Category Refinement*: The details from the earlier causal uncertainty measures and from the scales can help suggest the removal of particular sounds as unsuitable for use in the particular sonic context.
- *16 - Evaluation*: The details and results are further analysed to produce the final evaluation results and summary of the evaluation.

4.4 Simplification Of The Framework

This evaluation framework consists of two stages, each with a number of steps, however it is envisaged that in future, when sounds and their subjective qualities are better know that some of the steps within the stages may be simplified or found to be redundant. The approach already uses several methods to help triangulation the results. Additional steps may be added to the framework where suitable techniques are found to fit within it. This will help the framework to expand to incorporate newly developed methods. Existing approaches such as Barrass's [17] Auditory Information Design or Coleman's [16] Sonic Mapping can be used to compliment each other as part of the *sound analysis* stage in Figure 3. The best time to apply this complementary approach is during the early design stages in the sonic interaction design process as these methods are helpful for understanding subjective experiences. Questionnaires and task directed user sessions can still be used for evaluation in the later design stages, once prototypes are available. These can be used to provide alternative task based information on the usability aspects of the auditory display and combined with a better subjective foundation of experience will help improve the auditory display's use, mappings, and user acceptance. Existing guidelines [42, 43, 17, 44] can be used in conjunction with this framework to help design sounds for auditory displays. An example of where aspects of the framework are applied in practise can be seen in a companion work in this conference, on public space auditory display design [45].

There is no how-to or best practise for using these techniques, either individually or collectively. The most appropriate way to adopt these subjective methods is to adopt one or two of the complementary techniques from the framework and use them in a small design exploratory to see the value they bring to address a particular design issue. The main goal of this paper is to provide a short review for practitioners to the available techniques and design framework. Researchers can also use these techniques and combine them with the approach suggested by Bonebright et al [46] for evaluating the perceptual properties of acoustic signals. This would provide an understanding into the salient perceptual and cognitive aspects for a particular set of sounds within the specific design context. A good practise found in too few of the papers reviewed is the online availability of datasets, script files, or other software with which to showcase the methods. A companion work [47] in this conference highlights this practise by making all the necessary files, scripts, and datasets available online with the exception of a small number of copyright sound files.

The evaluation approach presented in this paper is ambitious, it aims is to help designers but additionally we hope to raise the importance and awareness of these methods within the community. This will encourage further explorations using subjective experience methods in auditory display. This work will continue to mature, presenting in this early development stage is an effort to elicit feedback and comments to assist future development of the framework and of these types of methods within auditory display design.

5 Discussion

The comparisons to other sounds/soundscapes, descriptions, emotional responses, confusion ratings, and language can help identify possible issues with mappings, use, and the acceptance of auditory displays. There are few studies in auditory display where these factors have been used as comparisons or where subjective measures have been questioned as complementary techniques. Commercial examples in the sonic interaction design field include the work in Peugot Citröen on interior car noises [48] and in Renault [49] on creating the sound of ‘sporty’ cars.

Food technology [50, 51] is another area which has shown a growing use of sensory profiling, projective mapping, and similar subjective experience studies to cater for the subjective and the hedonic aspects of experience. This type of consumer perception research has been used by companies to address both tactical and strategic research goals. Customer purchase decisions are influenced by perceived quality meaning this type of research can positively affect the outcome [52]. This can be seen in practise where the fruit juice company, Tropicana® created their *Grovestand Orange Juice* (now rebranded to *High Pulp*) using this type of research which showed the pulp was one of the key factor’s in customer’s perception of the product [53, 54]. Another commercial example is the Creative Design [55] design methodology which used systematic experimentation of product attributes to help in the development of new products. This methodology was first used by Stabburet A/S in Norway during 2001 to develop *Pasté*, a new version of their popular liver pâté. The product was well received in the market and the methodology has since been used to develop further products. The results of the study were found to be easy to communicate within the group and helped provided directions for future developments. The work presented in this paper on subjective experience methods and on the design framework can help produce similar results and benefits for auditory display designers.

Interaction design as a wider field has recently placed more attention on the discovery of the subjective aspects of products, interfaces, and interactions [56]. A number of the techniques have been used in interaction design research including the repertory grid. Hassenzahl and Wessler used the repertory grid technique and found “*the differences between artefacts, manifest in the personal constructs a group of individuals comes up with, is the design relevant information that should being the design space to life*” [57, p444]. They found using the method to explore competing designs produced six construct classes which broke down into design principles, quality of interaction, quality of presentation, hedonic quality, and adequacy concerns. In particular, the method provided concrete design relevant information and abstractions based on the derived constructs, which help further analysis and pointed directions for future development. The method helped to point out the important topics or factors without requiring a prior knowledge of them. The wide variety of analysis that could be applied to it help highlight its sensitivity to individual beliefs, needs, attitudes and perceptions. The mixture of complementary methods that can be used with the repertory grid in the design framework can help produce this type information and supplement it with results from the methods. This will ensure more design relevant information is elicited by the auditory display designer.

The use of the similar subjective experience methods, such as those mentioned in this review in practise will help provide similar design relevant information. While some these methods may not be as ‘rich’ as the repertory grid they can still provide additional insights on other facets of an individual’s subjective experience. A number of the methods overlap in terms of what is needed from participants and as a result a single experimental session can easily generate data which can be analysed by several of the methods. The listening test approach [58] asks participants to write verbal descriptions of what they have just heard. These descriptions are similar to the personal constructs collected with the Repertory Grid method [12, 13], the key sounds found using the Sonic Map & Earwitness approach [16], and when described in more detail are similar to the short stories in the Earbenders method [17]. Previous studies [59] have shown how the Repertory Grid method [12, 13] and Ballas’s causal uncertainty method [35] can be used on the same set of collected responses to analysis different yet complementary aspects. The similarity scaling technique uses direct scaling of sound stimuli and as such it requires a separate experimental session, which is perhaps advantageous as it focuses participants on the attributes being scaled rather than overloading them to do this task and also to provide written descriptions. This method could be potentially used with context-based ratings [46], sorting tasks [60] and discrimination tasks [35]. There are few examples where scaling and listening test approaches have been combined and it is hoped by highlighting the possibilities for overlap in this review it will encourage future research.

6 Conclusions

This paper introduced and reviewed a number of subjective experience methods with a focus on their application within the domain of auditory display. Reflections from these methods were used to highlight the advantages and disadvantages of these methods. The area of overlap where this methods could be used to compliment each other was explored. The results from these studies have shown there is an increasing awareness and focus on beliefs, needs, attitudes and perceptions of people. The use of these types of method will help to uncover the mental constructs used by listeners’ and the salient cognitive attributes of sounds. A design framework for auditory display incorporating these methods was presented and highlighted where methods could complement each other. A list of practical and hands-on references have been provided to help guide newcomers to these methods and aim to help them determine, which is the most appropriate for their particular questions and design needs. We would recommend consulting someone with expertise in the methods, particularly those using detailed statistical analysis, before using these on a specific project.

The subjective experiment methods and design framework described in this review will help to enable the evaluation of sounds for use in real auditory display and sonic interaction design situations. This review has provided an overview of techniques, which when applied can help deepen knowledge and contribute to answering the question raised by Hug [1] about how to design sounds for ubiquitous technology and situations. Finally, we hope that this review will help increase and create new collaborations between researchers interested in developing auditory displays, that consider people's subjective experiences as part of the early conceptualisation stages of design.

7 Acknowledgements

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