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Audiovisual sonifications: A design map for multisensory integration in data representation

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Abstract: In the field of data sonification, the construction of meaning is hampered by the lack of shared perceptual codes derived from common modes of perception, as it happens for the visual register. In this paper, we re-organize knowledge from previous experimental projects to build the foundations of future work in data representation. This experimental investigation aims to identify patterns in the translation process from different sensory modalities. To this end, 80 audiovisual sonifications have been collected and analyzed through phenomenological analysis with the goal of recording sensory correspondences. The resulting cross-sensory design map is a visual synthesis of the analysis, and it has a dual function. In the research domain, it proposes testable hypotheses for a systematic approach to data sonification. In the practice, it offers a space that is based on shared conventions that aim to standardize the actions and the choices of both sonification experts and communication designers.

Keywords: data sonification; visualization; cross-sensory design; perceptual codes.

1. Introduction

The definition of sonification evolved mainly in the context of the International Community for Auditory Display (ICAD) annual conferences, which most contributed to research in this field. Analysis of ICAD conferences shows a double tendency: from one side, the field looks to attest itself as a scientific technique - which raises issues of objectivity on the knowledge attained through the sense of hearing (Neuhoff, 2019; Roddy and Furlong, 2014). On the other side, there is a desire to address a broader audience through a language that can be universally understood (Supper, 2013). This ambivalence is also reflected in the production of sonification projects, which do not move uniformly, rather, it is characterized by a high number of autonomous interventions, often on an a-theoretical basis. This last aspect is considered crucial in hindering the formalization of a theory that is distinctive and shared.

1.1 Rationale and background

The theoretical foundations that drive sonification come from a multitude of disciplines. As with all research based on an interdisciplinary endeavour, the obstacles are diverse: from the different theoretical orientations of the discipline to the very terms used to define the field. Interdisciplinarity can be a point of strength and creative potential. At the same time, different interpretations may prevent the development of a single and shared theory. Interdisciplinary dialogue is fundamental to progress, which is why the sonification community aspires to develop a common language that can integrate different ways of talking, designing, and analysing. To date, general contributions to the theory are numerous (e.g., Kramer, 1994; Kramer et al., 1999; Vickers & Hogg, 2006; de Campo, 2007; Nees & Walker, 2008, 2011; Hermann et al., 2011; Grond & Hermann, 2012; Supper, 2012; Nees, 2019; Neuhoff, 2019; Worrall, 2019; Lenzi, 2021), but a comprehensive theoretical paradigm that can guide research and practice has yet to be articulated.

In order to lay the ground for standardized terminology, less open to interpretation, the community recognized the need to address multiple taxonomic descriptions. A number of papers examined ways of mapping data to sound, in relation to the type of data. Walker & Lane (2001) and Dubus & Bresin (2013) conduct a systematic review of acoustic representations mapped to physical and scientific data respectively and offer guidelines to support the design of effective sonifications. Other contributions address designers. Vickers & Hoggs (2006), Grond & Hermann (2012) rely on consideration of aesthetic design strategies derived from comparisons with musical compositions to improve the communicative function of sonification. Bearman & Brown (2012) investigate who the authors of sonifications are, thus obtaining a picture of the disciplines and tools involved in the practice. Additional contributions assess the end-user. Vogt (2011) helps define parameters for an objective evaluation through which designers can draw appropriate conclusions on the type of sonification that is best suited with respect to the end-user. Walker & Nees (2011) discuss how auditory displays can be classified based on their function. The organization of auditory display functions into the three categories of alert function, status or progress indication function, and data exploration function, are a sufficiently accepted approach (see Buxton, 1990; Kramer, 1994; Walker & Kramer, 2004). In Toward a data sonification design space map, de Campo (2007) presents a design tool to guide the choice of the most suitable sonification method. de Campo's contribution paves the way for Worrall's (2009) formalization of techniques. The types of interfaces used in an auditory display are organized on a continuum that blurs the boundaries between the three approaches (discrete-point, model-based, and continuous) identified by the author. Barrass (1998, 2012) advocates for a design approach that pushes for an aesthetic turn in sonification. As a synthesis of his investigation, he proposes the TaDa - task-oriented (Task) and data-sensitive (Data) - Method for designing useful sonifications. This method defines a space dedicated to perception in addition to the context and the information necessary to complete the task, the dimensionality, the organization, and the relationship to the data.

All these interventions testify a progressive move towards a design-like approach that begins with the theoretical framework, is aimed at defining a shared language and terminology, and proceeds to identify design tools. The most recent contribution to the construction of an increasingly comprehensive design framework, which attempts to bring together all the aspects illustrated above into a single design tool is the Data Sonification Canvas (Lenzi, 2021). The canvas' main goal is to support designers that choose to adopt sound as a method of representing and communicating information to the public. Unlike previous efforts, Lenzi offers a comprehensive protocol that looks at the end-user at every stage of the design, with the goal of creating sonifications that are useful in real-world contexts and of broadening the reach of sound as a method of data representation.

1.2 Codes for acoustic perception

The sonification community often welcomes examples from other fields, seen as both a resource for potential mutual learning and as a strategic option for building momentum (Supper, cit.). However, the practice seems more devoted to solving immediate real-world problems which result in solutions that are neither widely shared nor offer contributions to general knowledge. The constant development of new techniques often reveals little awareness on the part of the designer and a lack of intention to create a replicable solution that would benefit others. This approach is referred to by Nees (2019) as the "audio for the sake of audio" and describes a body of largely a-theoretical work that continually develops new techniques without evaluation. As a consequence, the field still lacks shared perceptual codes that, as in the case of visual representation, derive from common modes of perception. Secondly, there is still a largely diffuse difficulty in 'learning through sound', for audiences that are not trained in listening to gather information. The present study should be viewed as a preliminary, experimental work that focuses on clarifying these aspects which we identify as extremely relevant obstacles to the diffusion of sonification as the auditory correspondent of visualization. The paper considers the existing relationship between the visual and the auditory modalities and resorts from material produced by the community itself through a series of apparently disconnected examples. Through the identification of common trends in the translation of data to sound we hope to ground the design of new sonifications on a more functional basis. We identify the integration of visualization and sonification as key to the acceptance of this new data representation method. We believe that sonification should be contextualized within existing cultural practices and should be considered wherever the visual approach only is not sufficient. Our approach recognizes that visual representation is fundamental to scientific literacy in that the study of data visualizations and graphs is an essential part of our research vocabulary. "Knowledge is the result of multiple interdependent notions that concur to legitimize new conclusions" (Scaletti, 2017). The description of a complex phenomenon with only one mode of representation may be useful at times but it is certainly not complete. On the other hand, sensory integration facilitates multiple interpretations and increases audience engagement. This study aims to design a perceptual space (the multisensory design map, see paragraph 4) based on shared conventions, where individual perceptual differences are minimized. The map is intended as a guide for a design process in which sensory associations achieve communication goals that would be too difficult to accomplish through visualization or sonification alone.

2. Methods: Sensory analysis in audiovisual sonification

Audiovisual sonification is a term used to describe information representations that intentionally integrate auditory and visual registers, so that both sensory stimuli are purposefully designed - as individual qualities and as complementary elements. Rather than providing new definitions, this article seeks to describe the fundamental features, identified during the research, which are useful to distinguish these sonifications from those involving stimuli belonging to different sensory systems (e.g., smell, touch). The final objective of this study is the mapping of sensory correspondences found in audiovisual sonifications. The term audiovisual was chosen among others - e.g., Lenzi calls it *visualized sonification* (2021: 58) - to place both sensory modalities on the same level, regardless of their relationship to each other.

During the analysis, we considered the three sonification methods (*Audification*, *Parameter Mapping*, and *Model Sonification*). However, audification appeared to be less suitable for inclusion in the definition of audiovisual sonifications. Over the course of the research, we found that audification projects that involve the collection of real-world soundscapes often lack a visual register that mirrors the information conveyed by the sound. With the notable exception of sonic walks. Projects such as, for instance, *Sounds of the forest* (https://tinyurl.com/2r5fy7k2) and *Sonic Cities* (https://tinyurl.com/52w38vh6), can be seen as a way of preserving acoustic experiences which are then integrated into a visual representation. Here, the visual register functions as a container, a setting, so that the aural register doesn't appear as a list of recordings but as a coherent narrative. As a result, audification projects with the aim of archiving are excluded from the sensory correspondence analysis. The identification of the audiovisual sonifications involved in the research is the result of the phenomenological analysis described below.

2.1 Defining the steps

The phenomenological analysis is aimed at detecting trends in the use of sensory correspondences in the context of audiovisual sonifications and consists of three main phases (see Figure 1).

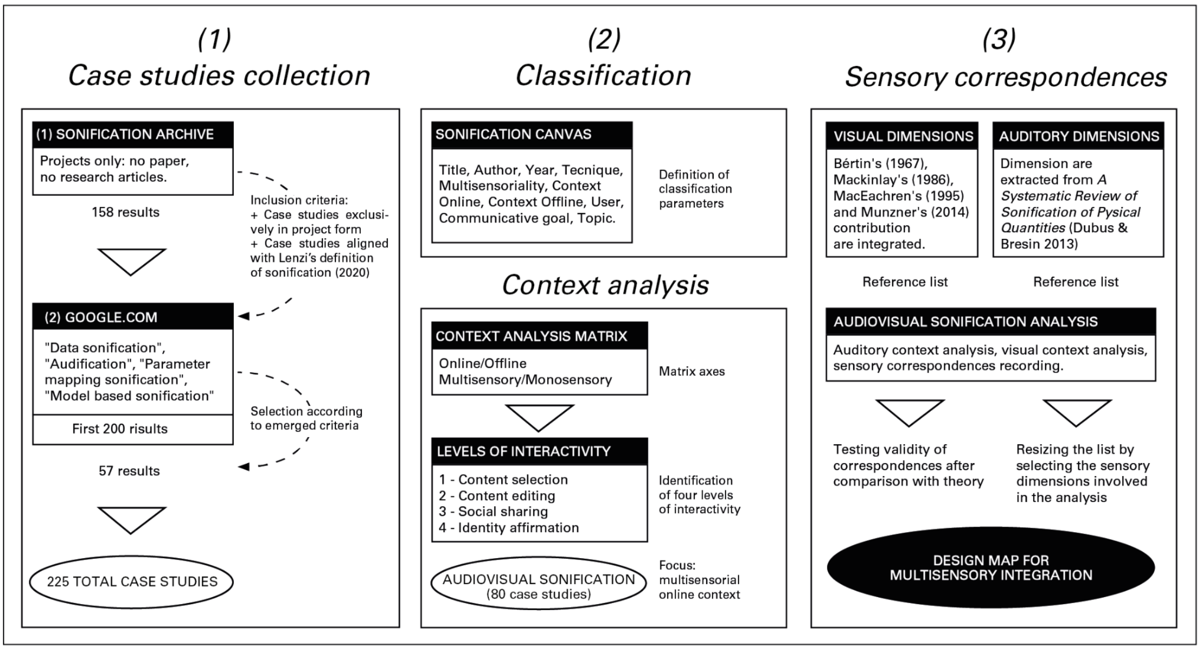

Figure 1. Research protocol organized in three steps: 1) Case studies collection, 2) Classification and context analysis, 3) Identification of sensory correspondences.

The first step involved the construction of the database, partially sourced from the Sonification Archive (https://sonification.design/), an online repository of curated sonification cases, and partly obtained through an independent online search. The collection of the sonification projects from the Sonification Archive overlaps with a preliminary exploration of the context and modalities of applied sonification. As a result of this phase, we developed two main selection criteria for projects to be included in the database. This allowed us to build an ideal case study collection that could be expanded in the future. In the first place, we observed that most of the sonifications hosted in the Sonification Archive are analogue or digital projects with sound contents accessible online, with only a minority of sonifications only presented through research articles or publications. We aligned our actions to this trend and removed from the official database all sonifications that were merely descriptive and did not allow the user to interact with the sonified artifact. The second criterion emerged as a need to collect sonification projects from which we could extract specific features, e.g., the sound component, the communication goal, the user, the topic, the context. For this purpose, we identified Lenzi's definition of sonification as the most suitable one. Lenzi describes it as "the use of sound, alone or in combination with other sensory modalities, to enhance the relationship with data for a specific user, in a specific context, with a specific purpose" (cit. 2021). This definition constitutes the basis of the second inclusion criterion. We thus selected 225 projects, which form the corpus of this study. The projects were then organized around an initial non-rigid classification, aimed at obtaining a general picture of the main contexts and modes of application of each sonification. The criteria for the organization were based on elements borrowed from the Sonification Canvas (Lenzi, cit.), a tool that schematizes the designer's implicit mental processes and accurately evaluates each of the steps involved in a sonification project. The choice of this tool is intended to facilitate the integration of visual and auditory representation. In fact, we believe that the current distance between the two modes of representation could be reduced if design took on the role of supporting reflection on how sonification operates. The results of our study support the belief that the integration of the auditory and the visual modes is a natural direction to drive change; both modalities share the same goals, modalities, and difficulties.

The analysis of the dissemination contexts further confirmed this interpretation (Figure 2). The distribution of case studies was denser where the dissemination modality involves a multisensorial online context that makes particular use of the visual medium. Therefore, the analysis was directed towards this small group of case studies, defined as audiovisual sonifications. This group was the real focus of a phenomenological investigation that led to identifying the sensory correspondences between auditory and visual representations and to position them on the audiovisual design map outlined in Section 4. The phenomenological analysis described above was conducted by the first author of the article. It is acknowledged that this approach comes with its own limitations, as well as a certain level of subjectivity. Future steps should involve an expert evaluation and a comparison between the results obtained from the analysis of the proposed use case collection.

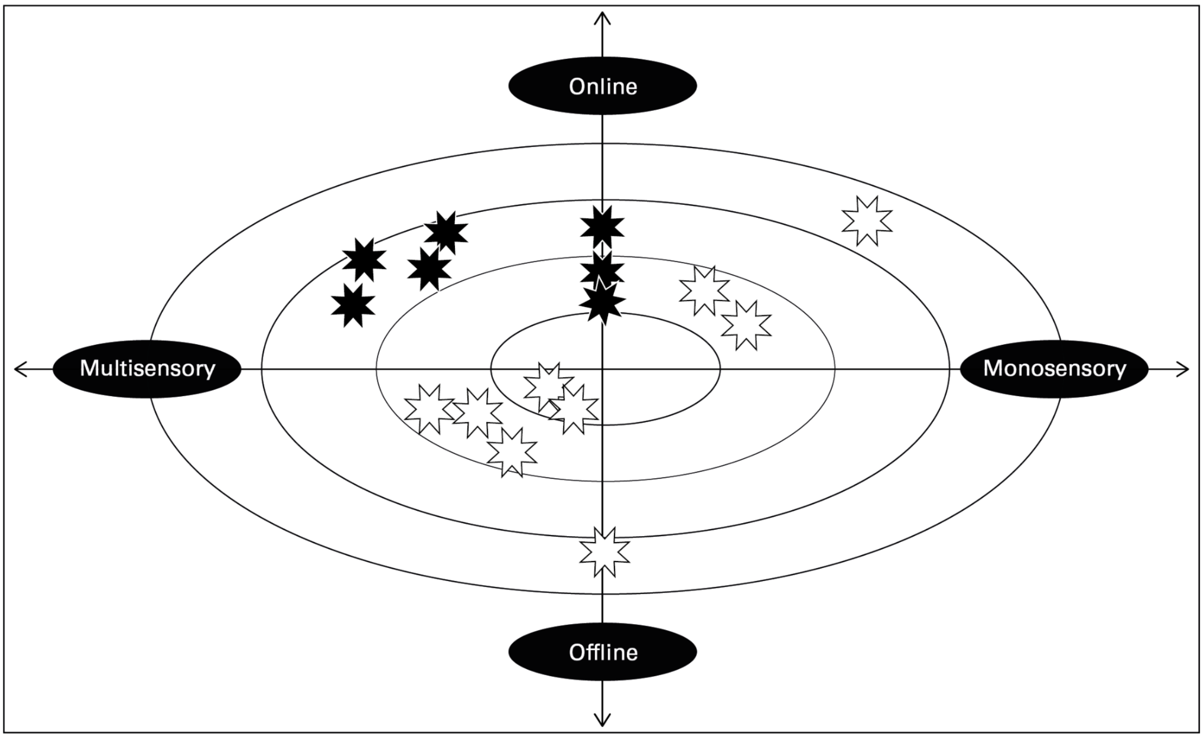

Figure 2. Case study analysis based on the distribution channel and the sensory quality. Audiovisual sonifications occupy the Multisensory-Online section.

2.2 Labelling audio and visual dimensions

To identify sensory correspondences, we defined two lists of visual and auditory qualities. These lists derive from the integration of the most relevant theoretical contribution to the fields of visualization and sonification. They constitute basic terminology and a reference for the analysis of case studies. Visual qualities derive from the reformulation of the codes of graphic representation of Bértin (1967), Mackinlay (1986), MacEachren (1995), Munzner (2015), and Roth (2016). Audio qualities were extracted from *A systematic review of Mapping Strategies for the Sonification of Physical Quantities* (Dubus & Bresin, 2013), where the authors run a systematic review of 60 previous studies to build the foundations of future design interventions in the context of sonification of physical quantities. The study was useful as a reference for the analysis and evaluation of the sensory correspondences (see Section 3). While analysing the selected cases, we identified several variations from the original lists. Based on the results of the analysis, the reference lists were adjusted accordingly. The construction of a definitive classification of the qualities of the visual - or auditory - register exceeds the purpose of this project. Rather, we intend to present a dynamic framework that can adapt to changes in context over time and that can integrate future research. The 16 visual qualities identified were labeled on a scale from V01 to V16 where 'V' stands for 'Visual'. These qualities are distributed over eight high-level categories: *Location*, *Size*, *Orientation*, *Color*, *Focus*, *Shape*, *Motion*, and *Disposition* (see Table 1).

Table 1. Classification of visual qualities identified in the sensory correspondence analysis. 'V' stands for 'Visual'.

Label	Visual Quality	Visual Category
V01	X Position	Location
V02	Y Position	
V03	XY Position	
V04	Angular Position	
V05	Length (1D)	Size
V06	Area (2D)	
V07	Tilt	Orientation
V08	Brightness	Color
V09	Saturation	
V10	Hue	
V11	Transparency	Focus
V12	Geometry	Shape
V13	Visibility	Motion
V14	Intersection	
V15	Rotation	
V16	Visual density	Disposition

Similarly, the eight audio qualities were labeled from A01 to A08 distributed over five high-level categories: *Intensity, Pitch, Timbral, Spatial, Temporal* (see Table 2). The identification of audio qualities refers, as mentioned, to a limited selection of case studies. As such, it is necessarily partial, and it is meant to gradually evolve with the integration of new cases.

Table 2. Classification of audio qualities identified in the sensory correspondence analysis. 'A' stands for 'Audio'.

Label	Audio Quality	Audio Category
A01	Volume	Intensity
A02	Frequency	Pitch
A03	Timbre	Timbral
A04	Spatialization	Spatial
A05	Ambient duration	Temporal
A06	Event duration	
A07	Reverberation	Spatial, Temporal
A08	Harmonic density	Pitch, Timbral

2.3 Identifying sensory correspondences

We use the term *sensory correspondences* to mark a clear distinction with the most common term *mapping*. The latter refers to the relationship between data and visual or audio qualities, while sensory correspondences occur when two or more qualities belonging to different sensory modalities are used to represent the same data or one of its characteristics. The act of defining takes place along two critical lines: the attempt to achieve a connection between the two sensory modalities - in audiovisual sonifications, the two coexist and support each other - and the desire to avoid a hierarchy of the senses, but rather to consider the artifact's final state.

Table 3 presents an excerpt of the isolation of sensory correspondences in each of the cases considered (in total, 80 sonifications). Audio and visual registers were initially described and analyzed individually for each project so that it was possible to discern how many qualities were involved in the data representation on a case-by-case basis. Once isolated, the qualities used in each case were compared to identify sensory correspondences.

Table 3. Example of sensory correspondences identified through the analysis of audiovisual sonifications. For the full list, see Caiola (2021).

Title of the case	Visual Quality	Audio Quality	Reference
Noisy City. Audible Data Visualization in Brussels (https://tinyurl.com/yuufxraw)	Color Hue	Volume	V10/A01
Multi-modal COVID19 analytics	Y Position	Frequency	V02/A02

(https://tinyurl.com/yttpc738)			
Landwaves (https://tinyurl.com/2p92rhhv)	Area (2D)	Frequency	V06/A02
iSonic: Interactive Data Sonification for Blind Users (https://tinyurl.com/2r5xh2x3)	Color Hue	Timbre	V10/A03
	X Position	Spatialization	V01/A04
	Color Brightness	Frequency	V08/A02
Hear the Blind Spot (https://tinyurl.com/8uhydpa3)	Y Position	Frequency	V02/A02
Sonification of COVID19 data (https://tinyurl.com/2p8pysrh)	Tilt	Frequency	V02/A02
Deep Space Sonata (https://tinyurl.com/yckr8avz)	Y Position	Frequency	V02/A02
	Color hue	Timbre	V10/A03
	Length (1D)	Ambient Duration	V05/A05
The Sound of Two Black Holes Colliding (https://tinyurl.com/2dt86v62)	Y Position	Frequency	V02/A02
The Sound of Rural Population Change in the US (https://tinyurl.com/mr49br9k)	Y Position	Frequency	V02/A02
Las Vegas Shooting (https://tinyurl.com/2887tzh3)	X Position	Event Duration	V01/A06
Commute (https://tinyurl.com/3vuwemdn)	Area (2D)	Frequency	V06/A02
	Color Hue	Frequency	V10/A02

3. Results: Incidence of sensory correspondences

Out of the 80 projects, 19 projects were excluded from the analysis because the two sensory modalities (audio and visual) were used to convey different information. We identified 108 sensory correspondences. We found this initial result of particular interest, especially if confronted with the results of Dubus and Bresin's study (cit. 2013). The author's review of mapping strategies between sound and physical qualities conducted on 60 projects identified 495 different mapping strategies – on average of 8.3 correspondences per project. Our analysis on sensory correspondences in audiovisual sonifications reports an average of 1,8 correspondences. The difference is remarkable. The main reason may be traced back to the specific documentation used to analyze the selected case studies. Dubus and Bresin

(2013), in fact, rely mainly on the documents and publications redacted by the authors of each sonification: it is safe to assume that the results were objective. Our research, based on phenomenological perceptual analysis, was conducted through a direct experience of each project: a strategy that necessarily involves a certain degree of subjectivity. As such, the results of the two studies cannot be properly compared. Still, this apparently inconsistent result led us to reflect on what seems to be a gap between the designer's intention and what the listener hears. The sonification community is actively reflecting on the effects caused on the listener by the interaction of multiple sound dimensions, as well as on the limitations to the perception of multidimensional acoustic data (Roddy, 2015; Carlile, 2011; Walker & Nees, 2011). Our approach based on sensory correspondences could be the catalyst of a research that helps define the limits of the auditory dimensions that can be concurrently perceived, in a parallel with the work initiated by Bértin (1967) with regards to the visual environment. To identify the most common correspondences, we conducted a first census. From there we could establish a ranking of the most useful correspondences, in the total number of projects analyzed. The ten most common are presented in Table 4.

Table 4. Ranking of the ten most popular sensory correspondences.

Occurrence	Correspondences	Reference
22	Y Position/Frequency	V02/A02
8	Visual Density/Harmonic Density	V16/A08
6	Area (2D size)/Frequency	V06/A02
6	Color hue/Timbre	V10/A03
6	Color hue/Frequency	V10/A02
5	Angular position/Event duration	V04/A06
5	Area (2D size)/Volume	V06/A01
5	Visibility/Event duration	V13/A06
4	Color brightness/Frequency	V08/A02
4	Length (1D size)/Ambient duration	V05/A05

3.1 Analogies evaluation

In the absence of a coherent shared categorization of mapping strategies in sonification, the choice of sensory correspondences remains, for the author of sonifications that is challenged with an audiovisual sonification, a critical design problem. The goal of our research is to lay the foundation for a tool that allows the sonification designer to determine which visual qualities to use in correspondence with a given audio quality (and vice versa). Our study identified the most common trends in the sonification community by recording the incidence of correspondences. The process described below leads to the construction of the cross-sensory design map where results are systematized. A second experimental phase will be required to evaluate the testable hypotheses - that have not yet been validated - for a systematic approach to data sonification.

By calculating the incidence of each correspondence between the audio and visual high-level categories, we were able to compare association strategies across the two sensory registers. A normalization factor was applied to the number of correspondences in each category. Our goal was to determine the relative weight of each sensory correspondence across our dataset. To compare mapping strategies in audio and visual categories, we normalized the data according to the number of mappings identified for these high-level categories. We computed the proportion of correspondence occurrence that match each high-level category for each row and column corresponding to these categories (see Table 5, Table 6).

Table 5. Distribution of correspondence occurrences for audio categories in relation to the visual register. The total number of sensory correspondences (Tc) is reported with the corresponding proportion normalized against the high-level visual categories (%).

	Location		**Color**		**Size**		**Disposition**		**Motion**		**Orientation**		**Focus**		**Shape**	
	Tc	**%**	**Tc**	**%**	**Tc**	**%**	**Tc**	**%**	**Tc**	**%**	**Tc**	**%**	**Tc**	**%**	**Tc**	**%**
Pitch	30	58,82	11	21,57	6	11,76	2	3,92	1	1,96	1	1,96				
Temporal	7	29,17	3	12,50	7	29,17			7	29,17						
Timbral	3	13,04	9	39,13	1	4,35							1	4,35	1	4,35
Intensity			4	40,00			8	34,78							6	60,00
Spatial	1	50,00									1	50,00				

Results show that as far as the auditory register is concerned, *Pitch* and *Temporal* categories are the ones used more frequently; while the most used categories of the visual register are *Location, Color, and Area (2D).*

As shown in Table 5 and schematized in Figure 3:

- *Pitch category* is strongly associated with *Location*, *Color*, and *Size*, while *Motion*, *Orientation*, *Focus*, and *Shape* do not seem to be widely used by designers.
- The second most frequent auditory category is *Temporal*. This quality is linked with *Location*, *Size*, *Motion*, and less frequently with *Color*.
- *Timbral category* occupies the third place. It is associated in total with five visual categories, among which Color and Position prevail.
- *Intensity* and *Spatial* are the least used categories. We find correspondence between *Intensity* and *Shape* to be particularly interesting and worthy of further investigation.

We repeated the process to assess correspondences in the visual register (see Table 6). The results show that the highest number of correspondences is detected in the categories related to *Location*, *Color*, and *Size*. The remaining categories appear to be clearly connected to a specific audio quality, a fact perhaps determined by the smaller and less heterogeneous number of recorded correspondences.

Table 6. Distribution of correspondence occurrences for visual categories in relation to the auditory register. The total number of sensory correspondences (Tc) is reported with the corresponding proportion normalized against the high-level auditory categories (%).

	Pitch		Temporal		Timbral		Intensity		Spatial	
	Tc	**%**	**Tc**	**%**	**Tc**	**%**	**Tc**	**%**	**Tc**	**%**
Location	30	73,17	7	17,07	3	7,32			1	2,44
Color	11	40,74	3	11,11	9	33,33	4	14,81		
Size	6	42,86	7	50,00	1	7,14				
Disposition	2	20,00			8	80,00				
Motion	1	12,50			7	87,50				
Orientation	1	50,00							1	50,00
Focus					1	100,0				
Shape					1	14,29			6	85,71

As shown in Table 6 and schematized in Figure 3:

- *Location* confirms the results of the previous analysis and reveals a strong correspondence with the *Pitch*, and - to a lesser extent - with *Temporal* categories.
- *Color* reveals analogies with almost all the auditory categories. The highest incidence is recorded with *Pitch* and *Timbral*.
- The remaining categories, as anticipated, reveal fewer correspondences. *Disposition*, *Motion*, and *Focus* are more frequently associated with *Timbral*; while *Orientation* is equally divided between *Pitch* and *Spatial*.

As a final step, we combined the results obtained from the two tables to determine the mutual coherence of the correspondences and their ranking, derived from the relative proportion normalized against the auditory categories (see Table 5 and Table 6). We considered the frequency of correspondences between the two sensory registers as well as between the qualities within the same register. Figure 3 illustrates the result of this integration process. The criterion for the evaluation of correspondences was carefully considered. For example, the *Focus/Timbral* correspondence in Table 6 reports a percentage of 100% but occurs for an insufficient number of cases (only once) to be considered an effective correspondence. To assign the right weight to each correspondence, it was first necessary to identify a threshold. We divided the total percentage of correspondences by the number of sensory systems in which correspondences occurred: *(100% / Nsyst) = threshold. This process was repeated for each auditory category of both sensory modalities. Finally, each correspondence was rated based on the following conditions:*

% > threshold = strong correspondence

% < threshold = weak correspondence

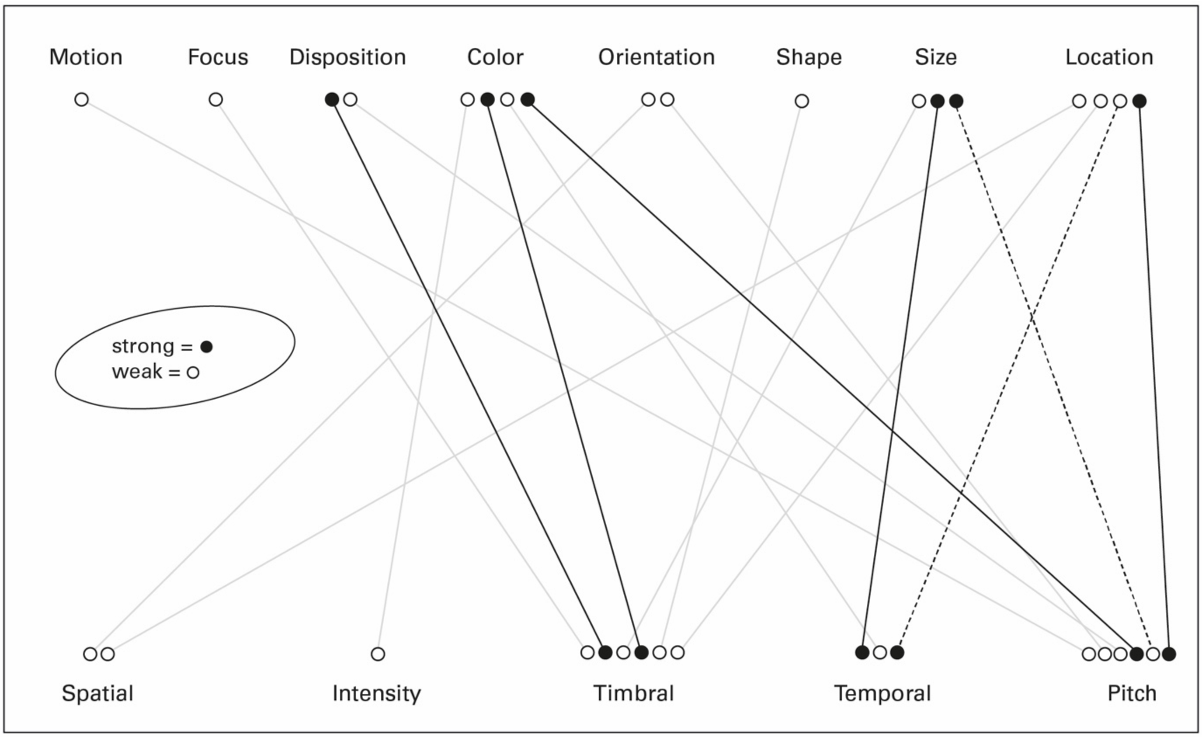

Figure 3. Representation of sensory correspondences' ratings obtained from the distribution evaluation for both auditory and visual qualities.

4. Audiovisual design map: Multisensory integration in data representation

Results of the analysis of the sensory correspondence informed the definition of an audiovisual design map, presented in Figure 4. The map provides an improved tool for a deeper comparison of the visual and auditory domains considering all sensory qualities at glance. The sensory registers were aligned, the biunivocal correspondences were isolated and rated based on the frequency with which they occurred in our dataset. We understand the map of mutual correspondences as an implicit validation of the selection criteria of the dataset, based on the definition of audiovisual sonifications. We then used the cross-sensory interactions emerging from the map to formulate a design proposal for the creation of audiovisual sonifications.

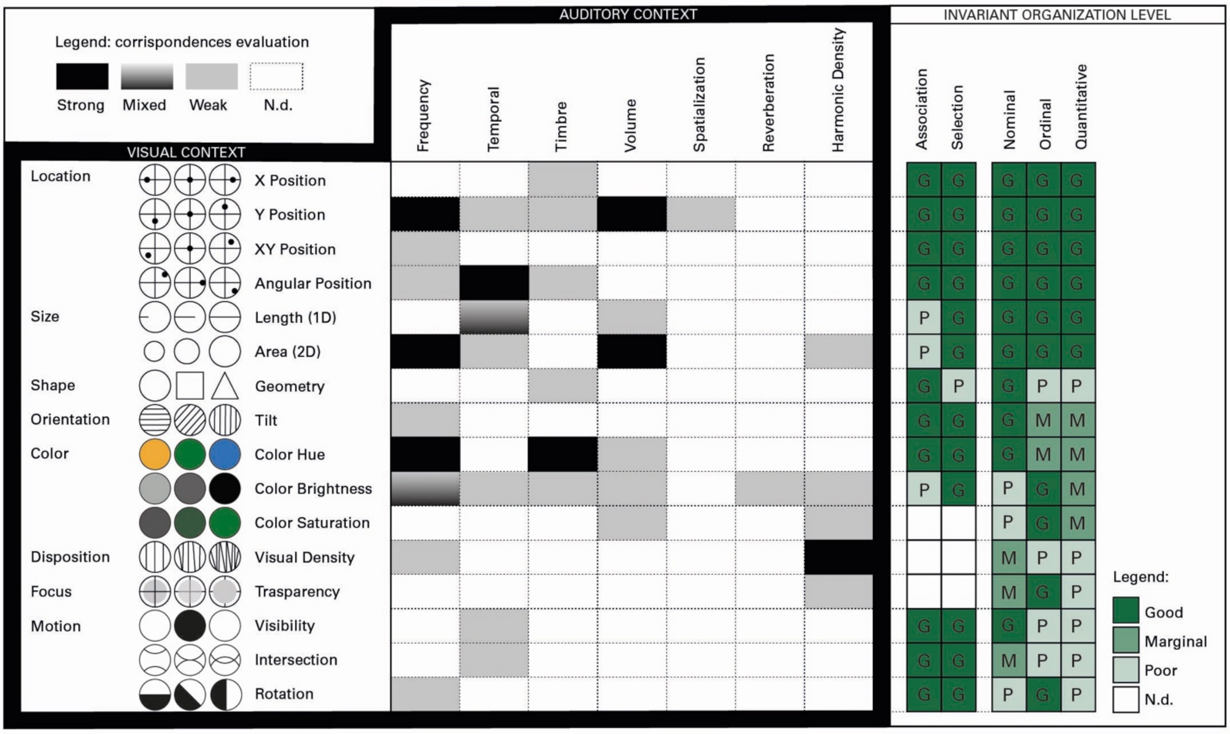

Figure 4. Audiovisual design map. The map originates from the analysis of the incidence of sensory correspondences in audiovisual sonifications.

This cross-sensory design map results from a reformulation of Bértin (1967), Munzner (2015), and Roth's (2016) theoretical approach, from which we extracted the visual qualities involved in our analysis. The map was then integrated with auditory qualities, and the audiovisual correspondences that emerged from the analysis were evaluated. In its current state, the map is a synthesis of the analysis of correspondences, as indicated through the intersection of columns (auditory qualities) and rows (visual qualities).

Observing the diagram, some considerations can be made. Strong correspondences are fewer than weak correspondences. They are identified especially between the qualities: *Area (2D)/Frequency, Angular Position/Temporal, Color Hue/ Frequency, Color Hue/Timbre, Area (2D)/Volume, Visual Density/Harmonic Density*. The map's visual representation is meant to facilitate the emergence of nuances in the sensory correspondences. It is also meant to be an easily scalable tool i.e., it is designed to accommodate future theories and practical insights. Three mixed correspondences were identified, i.e., correspondences that appeared in both sensory registers but have greater expressive power in one modality compared to the other. We believe that these correspondences deserve further investigation, with a particular focus on the context in which they appear to be weaker. We plan to continue the analysis to define the most appropriate role and context of these correspondences one at a time. Although the map was originally intended to serve as an overview and conclusion of the analysis, in the near future it may develop into an effective tool for audiovisual sonification and multisensory design. This may be accomplished by incorporating the map in a real-life context by sonification experts and designers. A validation process is needed to confirm the results – the sensory correspondences and their evaluation - as well as the method.

As a result of the alignment between sensory registers, auditory qualities have been integrated into the original Bértin's evaluation of invariant components. In the visual culture, components are organized in three levels: nominal, ordinal, and quantitative. Understanding the nature of the component is fundamental to guiding the design and the selection of the best graphic form. Our map integrates auditory qualities into these assessments, and this might suggest that two sensory qualities linked by a strong correspondence might share the same expressive potential, and therefore both could represent the same type of data. In addition to its first function, the map can be used as a generative tool for the integration of different sensory information into data representations. The tool would allow both visualization and sonification designers to explore trends and choose to reuse, validate (or refute) existing options, or explore new paths. We intend the design map and the results of this research to support the integration of sonification and visualization. The desired outcome is guidelines for the cross-sensory design of data representation projects in which the designer consciously controls the balance between different sensory modalities. We believe the value of the map lies in providing an alternative to data representations that rely only on one sensory modality. The authors advocate for a reconsideration of the competitive attitude between sonification and visualization in favour of joint efforts toward multisensory integration.

5. Conclusion and perspectives

We conducted a phenomenological analysis on a selected dataset, with the goal of detecting relevant sensory correspondences in audiovisual sonifications. We see this project as a contribution to the advancement of the field of sonification drawing upon the achievements of the community while avoiding the proposal of new theoretical infrastructure. Rather, we aimed to systematize existing - though implicit - trends to help bridge the perceived gap between theoretical knowledge and practice. In this way, isolated, heterogeneous research, typical of a pre-theoretical stage of the field, could gradually fit together and be incorporated into a general framework of understanding, where successes would be magnified, and errors would not be repeated. This process is dual. From one side, it consists of a pre-translation aimed at capturing the lack of a distinctive and shared formalized theory as the issue that directly affects the sonification community. Here is where the multisensorial design map is positioned. The second phase is explicitly translational and will involve the transition from text instruction to the physical artifact, in other words from the design map to the concrete application and validation of the consideration that emerged. Essentially, the purpose of this map is to provide a faster evaluation of alternatives, improve understanding of results, and highlight unproductive choices so that choices in the cross-sensory design of data representation can be aligned. The correlations and patterns that emerged are not necessarily weak, even though the analysis was limited to a small number of cases. Unavoidably, the design process generates several statements that may follow different logic and do not entirely correspond with one another. Even though there might be contradictions, multiple positions, and incoherent narratives, it is essential to remember that we are witnessing a system in transition.

5. References

Barrass, S. (2012). The aesthetic turn in sonification towards a social and cultural medium. AI & SOCIETY, 27(2), 177–181. https://doi.org/10.1007/s00146-011-0335-5

Barrass, S. (1998) Auditory Information Design. Doctoral Thesis. UMI Order Number: AAI9936133, The Australian National University (Australia)., http://hdl.handle.net/1885/46072.

Bearman, N., & Brown, E. (2012). Who's sonifying data and how are they doing it? A comparison of ICAD and other venues since 2009. Proceedings of the 18th International Conference on Auditory Display. ICAD, Atlanta, GA, USA.

Bértin, J. (1967). Sémiologie graphique: Les diagrammes, les réseaux, les cartes. Éd. EHESS.

Buxton, W. (1990). Using our ears: an introduction to the use of nonspeech audio cues. In E. Farrell (Ed.). Extracting meaning from complex data: processing, display, interaction. Proceedings of the SPIE, Vol 1259,124-127.

Caiola, V. (2021). Sonificazioni Audiovisive. Analisi fenomenologica delle corrispondenze sensoriali per la costruzione dei codici di percezione acustica [Master Thesis]. Politecnico di Milano.

Carlile, S. (2011). Psychoacoustics. In T. Hermann, A. Hunt, & J. G. Neuhoff, The Sonification Handbook (pagg. 41–59). Logos Verlag.

Campo, A. de (2007). Toward a data sonification design space map. Proceedings of the 2nd International Workshop on Interactive Sonification. ISon, York, UK.

Dubus, G., & Bresin, R. (2013). A Systematic Review of Mapping Strategies for the Sonification of Physical Quantities. PLoS ONE, 8(12), e82491. https://doi.org/10.1371/journal.pone.0082491

Grond, F., & Hermann, T. (2012). Aesthetic strategies in sonification. AI & SOCIETY, 27(2), 213–222. https://doi.org/10.1007/s00146-011-0341-7

Hermann, T., Hunt, A., & Neuhoff, J. G. (A c. Di). (2011). The sonification handbook.

Katharina, V. (2011). A quantitative evaluation approach to sonifications. The 17th International Conference on Auditory Display. ICAD -2011, Budapest, Hungary.

Kramer, G. & Santa Fe Institute (Santa Fe, N.M.) (A c. Di). (1994). Auditory Display: Sonification, audification, and auditory interfaces. Addison-Wesley.

Kramer, G., Walker, B., Bargar, R., & International Community for Auditory Display. (1999). Sonification report: Status of the field and research agenda. International Community for Auditory Display.

Lenzi, S. (2021). The design of data sonification. Design processes, protocols and tools grounded in anomaly detection [PhD Thesis]. Politecnico di Milano.

MacEachren, A. M. (1995). How maps work: Representation, visualization, and design. Guilford Press.

Mackinlay, J. (1986). Automating the design of graphical presentations of relational information. ACM Transactions on Graphics, 5(2), 110–141. https://doi.org/10.1145/22949.22950

Munzner, T. (2015). Visualization analysis and design. CRC Press, Taylor & Francis Group.

Nees, M. A. (2019). Eight Components of a Design Theory of Sonification. Proceedings of the 25th International Conference on Auditory Display (ICAD 2019), 176–183. https://doi.org/10.21785/icad2019.048

Neuhoff, J. G. (2019). Is Sonification Doomed to Fail? Proceedings of the 25th International Conference on Auditory Display (ICAD 2019), 327–330. https://doi.org/10.21785/icad2019.069

Roddy, S. and Furlong, D. (2014). Embodied Aesthetics in Auditory Display. Organised Sound, 19, pp 70-77 doi:10.1017/S1355771813000423

Roddy S. and Furlong D (2015) Sonification listening: An empirical embodied approach. In: Vogt K, Andreopoulou A and Goudarzi V (eds) In: Proceedings of the 21st international conference on auditory display (ICAD 2015), Graz, Austria, 6–10 July 2015.

Roth, R. E. (2016). Visual variables. In The International Encyclopedia of Geography (pagg. 1–11). Wiley.

Supper, A. (2012). Lobbying for the ear: The public fascination with and academic legitimacy of the sonification of scientific data. [Doctoral Thesis]. Maastricht University.

Vickers, P., & Hogg, B. (2006). Sonification Abstraite/Sonification Concrete: An 'æsthetic Perspective Space' For Classifying Auditory Displays In The Ars Musica Domain. Proceedings of the 12th International Conference on Auditory Display. ICAD, London, UK.

Walker, B. N., & Kramer, G. (2004). Ecological psychoacoustics and auditory displays: Hearing, grouping and meaning making. In Ecological Psychoacoustics. Elsevier Academic Press.

Walker, B., & Nees, M. A. (2008). Encoding and representation of information in auditory graphs: Descriptive reports of listener strategies for understanding data. Proceedings of the International Conference on Auditory Display. ICAD 2008, Paris, France.

Walker, B. N., & Lane, D. M. (2001). Sonification mappings database on the web. Proceedings of the 7th International Conference on Auditory Display, 281.

Walker, B. N., & Nees, M. A. (2011). Theory of Sonification. In The Sonification Handbook.

Worrall, D. (2009). Sonification and Information: Concepts, Instruments and Techniques [PhD Thesis]. University of Canberra.

Worrall, D. (2019). Sonification Design: From data to intelligible soundfields. Springer.

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