VPS VIBRATIONS IN PHYSICAL SYSTEMS
DOI: 10.21008/j.0860-6897.2022.1.06
Vibrations in Physical Systems, 2022, 33(1), 2022106

The Role of the Iconicity of Sound Within the Multisensory Environment

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Abstract The iconicity of perceived content includes all associative aspects that are intuitively attributed to the stimuli. Sound thus communicates information on the nature of its source. Associative content is essential for the fit of specific sounds in the total background and in the whole multisensory environment. Psychoacoustic parameters of sound contribute to the overall perceptual appearance of auditory elements, but iconicity and semantic content are determining the meaning of sound, which is most important to the listener. An objective iconicity analysis is introduced for the assessment of multisensory aspects of an environment. It is configured for the intuitive selection of appropriate images from a large dataset. In contrast to the common procedure of image-based soundscape analysis, the pictures refer to perceived single aspects, features of materials touched, functional aspects of processes, and emotions. It has successfully been applied to visual and tactile stimuli. Its expected benefit for sound evaluations is discussed.

Keywords: Sound perception, synesthetic design, iconicity, touch sounds.

1. Introduction

Situations of daily life are usually characterized by a variety of stimuli approaching the perceptual system via the different senses. From soundscape research, it is known that the contribution of auditory sensation plays an essential role for orientation, the perception of ambience and emotions [1]. However, the auditory events are usually not isolated, and the perceptual system tends to integrate them into a plausible *whole* of world experience – the *holistic appearance* of the world. It thus provides a multisensory Gestalt of the environment perceived. In this regard, the assessment of a complex acoustic environment requires the inclusion of all perceivable sounds and the related stimuli of the other senses. ISO/TS 12913-2 thus demands to 'assess all sounds perceived in an environment in all its complexity' [2].

In the perceptual system, integration of the multisensory data streams configures a plausible model of the exterior world. Missing data is substituted, such as the hidden parts of a form that is recognized, or words of a speech that are temporary masked by disturbing noise. Contradictory data are best possibly eliminated in a manner that provides a *harmonized* appearance without perceptual conflicts. The holistic appearance persists until contradictory data are available that cannot be matched. This occurs, e.g., in the case of an unexpected technical noise that manifests itself within a quiet, presumably undisturbed, natural environment. The provoked perceptual conflict raises attention and motivates the search for a cognitive solution, or at least a plausible explanation.

For the assessment of multisensory configurations, it is essential to find the most important attributes that enable the perceptual fit of sensations into the whole. For multisensory integration, correlations of single perceived features are important. These crossmodal correspondences enable plausible integration across the borders of the single senses [3]. In the auditory field, psychoacoustic parameters such as the loudness, sharpness, tonality etc. of sounds are those elements that come into effect for connections to parameters of vision, haptics, and the other senses.

However, besides these elementary correlations, the perceived fit of single stimuli into a complex environment is mainly facilitated by what is communicated. In addition to the semantic aspects of spoken language, a specific role is taken on by the elements that are the subject of associative references and thus convey aspects of *iconicity* [4]. The *iconicity of sound* includes all associative aspects of any signal. It includes information on types and engines of vehicles, kinds of animals, climate phenomena like wind and rain, material of surfaces touched, musical instruments, accurate and defective functioning of technical devices, emotional condition of speaking persons, etc. Amongst other applications, film sound design takes care of the appropriate associative content of sound. This especially applies to sounds that point to material properties – materializing sound indices [5]. During haptic operations, the touching of surfaces generates such characteristic sounds. In terms of product design, touch sound evaluation is essential for material identification and the perceived authenticity of surfaces [6]. Furthermore, these auditory stimuli transfer emotional content and define the quality appearance of products that are frequently touched.

Iconic aspects are also connected to spoken language. They occur in the intuitive connotations of pronunciation, intonation, and speech melody. However, words of any language bear some vagueness and uncertainty. A translation of terms from one language to another is seldom possible with a precise transfer of meaning. In the field of acoustics, this finding is confirmed by experience with translations of soundscape vocabulary from English into 15 languages [7]. In most cases, two or three words were required to (almost) clearly transfer meaning from one language to the other.

Speaking about sounds becomes easier in cases where the voice is used to reproduce them with some typical aspects. Onomatopoeia combines the sound replay using the voice with semantic cues. An example is the rattling sound of the spoken word 'rattle', which in German is equivalent to 'klappern'. Interestingly, this example shows that the aforementioned vagueness of translations often also applies to the non-semantic aspects of language. Although both words sound different in the respective languages, they express the features essential for clarification of the iconic reference.

Within typical soundscapes, associative aspects of sound appear to be decisive, regardless of whether or not the sound sources fit into the expected multisensory features of the environment. However, it is usually not clear which features of a sound convey associative content and exactly which images or attributes are thereby evoked. An example is mentioned below how laboratory methods serve to clarify the iconicity and thus identify the most decisive aspects of all relevant stimuli.

2. Multisensory relations via iconicity

In case a given sound does not damage the ear or mask communication, the information content becomes essential for its subjective effect. Besides semantic content, aspects of iconicity connect the imagination of the multisensory Gestalt of the source – which may be understood as a representation of a 'perceptual object' – to the perceived environment. By this means, the source can preliminarily be identified from auditory features. It is just an estimation based on sensory data. However, the estimated source comes into subjective existence. We do not perceive a sound that may possibly be attributed to a bird—instead, we hear a bird. This kind of configuration of cognitive models happens all the time. We hear a large trolley, a small electric car, or a leaf blower. An angry old man can be identified from the sound of his voice without needing to understand the content of his speech. But without proof from the other senses, the evaluation of the nature of the source remains preliminary. The initially detected leaf blower could also possibly be a vehicle.

The annoyance caused by a sound is thus not only a function of psychoacoustic parameters, but also of the identified nature of the source. It furthermore triggers emotions such as fear of danger, expectations of festivities, etc. In combination with the single auditory events that are perceived, a perceptual representation of the total environment is generated. The fit of the identified nature of a single source, i.e. its multisensory representation in the total perceived environment, is decisive for its subjective effect.

The identification of a sound source by means of its iconic aspects requires intuitive knowledge about the source. At the very least, the correlation of the sound and other sensory data must have been perceived before. Learning processes are thus a precondition for the analysis of iconic features. However, in the case of unknown sounds, a hypothesis is generated via crossmodal correspondences, which refer to psychoacoustic parameters. In this manner, objects and processes can be estimated to be, e.g., 'a heavy, slowly moving, big object', 'a sharp cutting process', or 'a sticky, rough surface'.

Iconic references can be very simple for single, homogenous sounds, such as the random wiping noise when a homogenous surface is touched, or the sound of a rolling ball. The example of a fully automated coffee machine shows that complex processes can cause sequences of very different sounds. Interruptions of a complex auditory sequence can also be of crucial importance for the iconic content. This can easily be verified in the case of a bouncing ball with its combination of short pulses and longer interruptions. If a strictly conservative psychophysical concept would be applied here, it would lead to completely ignoring the breaks between two pulses, because during a break – without a stimulus – no sensory response could exist. The duration of the breaks between two pulses, however, is an essential iconic feature to understand the process behind them. The same applies to the sequence of pulses that indicate walking or a tennis match.

The perceived position of the sound source and the sensory intensity with respect to the environment also serve as iconic features. Moreover, the perceived intensity of sound [8] must fit to the localised, or assumed, position of the source. Kendall uses the term *perceptual magnitude* [9]. This is especially important for the adjustment of artificial sources, like loudspeakers. If a bird song is replayed in a quasi-natural environment, its loudness must not exceed the habitual range.

In short, iconic references enable intuitive rating of the fit of specific sounds in the total background of all sounds and, furthermore, in the whole multisensory environment.

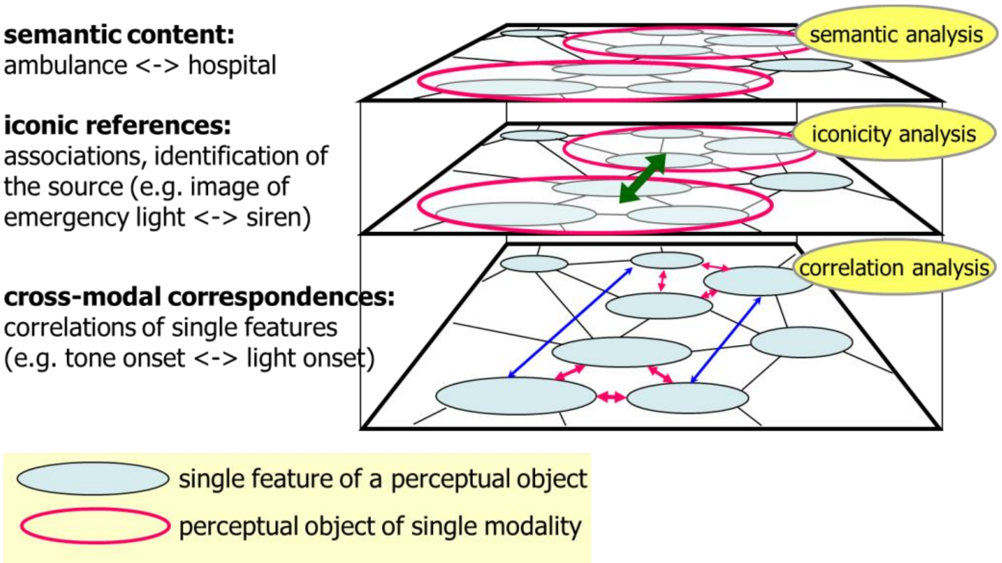

Figure 1. Perceptual overlay of correspondences, iconic and semantic content – sketched by the author [15].

Although the associative features of stimuli are of major importance throughout daily life, they have not been the focus of perceptual research. Various terms have been used in literature. *Iconic code* is used in the field of semiotics [10]. A historic German publication on the perception of adolescents who lost their eyesight uses the word *Dingwahrnehmung* (object perception), which refers to the fact that sound often leads to the imagination of real objects [11]. Auditory processes that identify the source are named *causal listening* by Chion [5]. Özcan and van Egmond use the term *semantic associations* [12], whereas Flückiger speaks of *1st order semantics* [13]. Nonetheless, a clear differentiation between associations/iconicity and semantic content is required. During early discussions, the author of this paper proposed the term *konkrete Assoziation* (concrete association) to clarify that most associations manifest themselves in the imagination of real objects from the world outside the individual perceptual system [14].

Figure 1 shows a diagram that explains the major processes of cross-sensory integration [15]. Crossmodal correspondences correlate basic – e.g. psychophysical – features of the various sensory streams. This enables iconic references across the senses, while semantic connections contribute on a higher level.

3. Examples of iconic features within sound

3.1. Touch sounds

Touch sounds are excited when surfaces are touched with the fingers or with the whole hand. Usually the friction at the area of contact causes a stochastic noise with a broadband characteristic. Although the loudness in most cases is quite low and the noise thus does not gain high conscious attention, it is still audible and contributes to the perceived features of surface and material. However, specific characteristics of the signal can increase attention. The sound may contain tonal components due to periodicity of the texture. Ear-catching low frequencies and roughness can result from stick-slip effects, which are connected to a pendular change between static and dynamic friction. Specific material properties and geometries of texture can add squeakiness to the sound. Even without tonality, high energy content at high frequencies can cause high sharpness of the sound.

Touch sounds are of great importance because they communicate the features and quality of surfaces, even in cases of soft and unremarkable sound properties. In product design, these iconic features are of high importance for estimation of the material used and its reliability. Analysis of iconicity is therefore the most important cognitive strategy for the multisensory relevance of touch sound (Fig. 2). It identifies the aforementioned materializing sound indices. Psychoacoustic parameters can contribute to the iconic appearance of surfaces in an unusual manner. The sharpness of these soft touch sounds is often not rated negatively, but may indicate high quality through the estimated fineness of the texture [6].

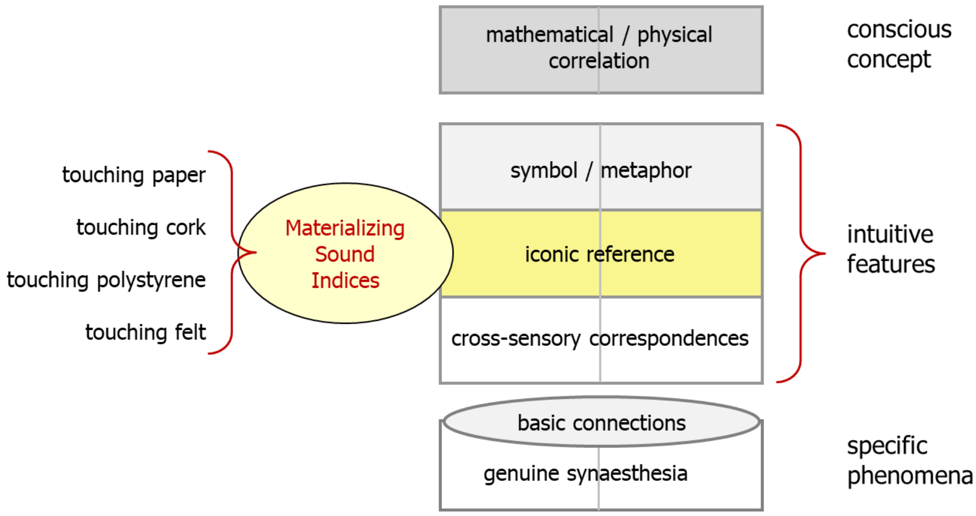

Figure 2. Iconic content of sound as an essential perceptual process of cross-sensory interactions [4].

3.2. Movement represented by sound

The auditory representation of movement within sound is of great importance, not only since the current discussion started around artificial sounds for electric vehicles. Naturally, fast movement of sound sources is represented by means of binaural hearing. However, from everyday perceptual experience it is known that a monaural sound itself can transfer information about processes of movement. The communication is based on psychoacoustic parameters and aspects of iconicity. It is thus also essential for numerous applications of functional sounds. As an example of the influence of basic psychophysical features, an increasing vehicle speed is sensed when tonal components are rising. Nonetheless, iconicity is also suitable to express acceleration. This happens – in the case of a broadband noise – with increasing loudness and sharpness, which demonstrates a similarity to wind noise. Admittedly, in some cases the distinction between basic correspondences and iconic features is not clear. In the case of the rising tonality, it could point to an inherent perceptual connection, or result in perceptual experience with engine noise. The close interaction between cross-sensory correspondences and iconicity is evident, and correspondences often shape the iconic reference.

As mentioned before, iconic features of sound are essential for film applications. They need to be applied by the Foley artists and special effect designers. The same principle is suitable for adding soft sounds to touch screen applications, such as a low-level sliding noise for the application of a virtual sliding bar, which clearly is identified as a touch sound. The artificial clicking sound of a virtual button is another example. Beside haptic feedback, it adds reliability via increased multisensory redundancy. If functional feedback is conveyed in parallel via various senses, the overall effect of disturbances of single channels can be reduced. For the avoidance of confusion caused by sensory overflow, it is essential that all contributing stimuli need to be of a low level, just slightly above the perception threshold. Furthermore, it requires refined cross-sensory alignment of all stimuli.

Iconicity is also essential for the correlation of musical pattern and visual movement [9]. Further examples of iconic representation of movement include the noise of a vehicle braking, the hiss of an air stream, the noise of moving tools such as a grinding noise, or the sound of writing on a blackboard with chalk.

3.3. Representation of sequential processes

As mentioned, both the series of sounds and intermitting breaks can contribute to the iconicity of a complex process. As a further example, Fig. 3 shows the sequence and spectral content of a firework rocket launch.

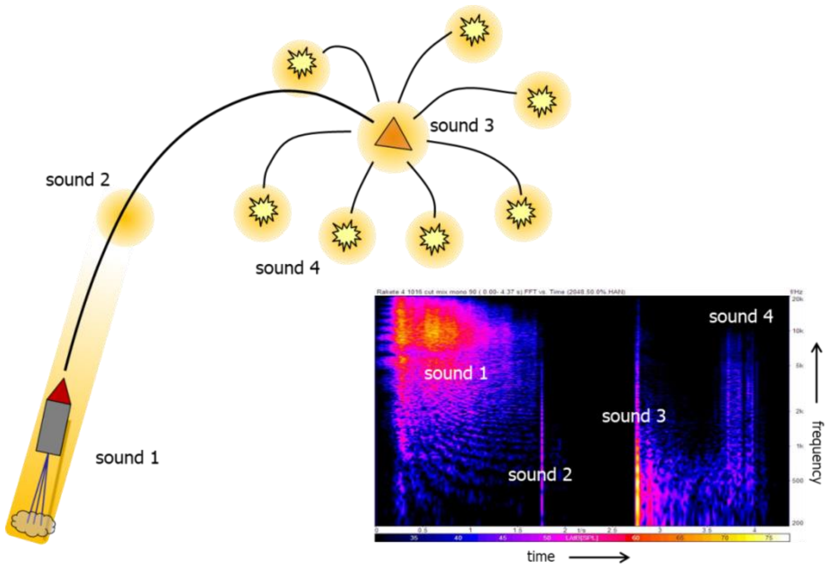

Figure 3. Complex time variant process of a firework's rocket launch, process steps and sound analysis.

It includes the start-off sound (1), blast away of the carrier rocket (2), explosion of the shell (3), and the flashing of the pyrotechnic material (4). The sounds express information on the size of the rocket and shell, the velocity of lift-off, the number of single illuminations, etc. The duration of the breaks provides evidence of the height of flight and the distance covered. In case the process is not observed visually, such information is facilitated for intuitive estimation of the visual appearance, i.e., configuration of a preliminary image. This image will include deviations from reality, but enables an understanding of the incidence. Iconicity connects the single audible events to shape the Gestalt of one identic process.

4. Evaluation of sound iconicity

A systematic approach is required for the evaluation of the iconicity of sound. From experience with the evaluations of other sensory inputs such as visual and tactile features, it is likely that an image-based method will lead to detailed knowledge of the iconicity of sound. Such methods are also appropriate for the analysis of taste and smell. However, images are often beneficially included with evaluations of soundscapes [16]. It is well known that the visual ambience of places plays an important role for soundscape assessment. Visual aspects are usually elements of a soundwalk [17]. In a laboratory environment, slides can substitute the in situ view. It also may help to equip the laboratory with appropriate visual elements [18]. Modern approaches make use of immersive virtual reality for laboratory applications [19]. Such visual aspects usually comprise holistic views of sceneries. The methodology proposed herein is different to such approaches, because it uses separate images for all perceivable attributes of sound, including associative aspects of psychoacoustic parameters, usage of tools, plausibility of processes, functional mapping, social aspects, and emotional connotations (Fig. 4).

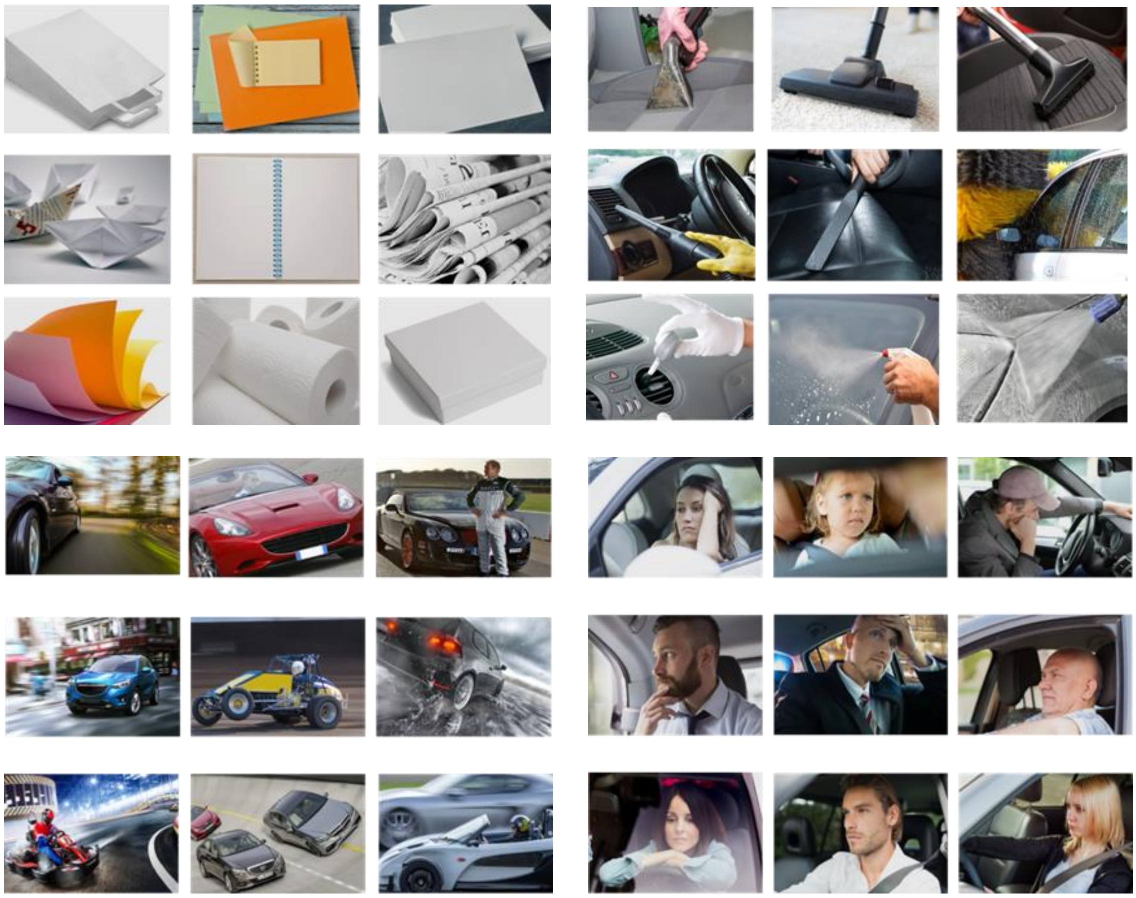

Figure 4. Examples from the large set of images for the assessment of materials (paper), processes (use of cleaning tools), driving (sportive), emotions (dissatisfied) – from top left to bottom right.

The proposed method combines image analysis with the subjective assessment of basic psychophysical features by means of semantic differentials and along rating scales. It has been developed in cooperation with the test institute SenseEngineers [20]. Test persons must select appropriate images from a large set of pictures. They do not know the categories, such as 'sportive driving' or 'feeling dissatisfied'. In the next step, the individuals evaluate the selected aspects for positive, neutral, or negative connotations. Finally, they provide written comments to explain their decisions. The test does not require a specific laboratory. It can be done by the test persons at home, where sounds are provided online and the results are returned interactively.

The extended methodology has successfully been used for the evaluation of the iconic content of various senses and is ready to include sound for assessment. The results are here referred to as a good example of what a systematic evaluation of iconicity means. First tests focused on the perceived quality of surfaces for a vehicle interior. The visual and tactile assessment provided a clear view of the aspects of iconicity. As an example, three types of leather grain applied to plastic surfaces were assessed, both on a visual and tactile level, by 114 individuals (Fig. 5). Flat plates as test specimens were sent to test persons, who did the assessment at home using their own PCs. In this way, a direct contact to the test conductor could be avoided, which enabled a brand neutral assessment that did not require a transfer of information on the institution that utilized the results. The effort of test performance regarding travel time and costs was thus reduced. However, specific questions and/or tasks need to be included to prove the capability of the individual equipment regarding image contrast, colour, light conditions, etc.

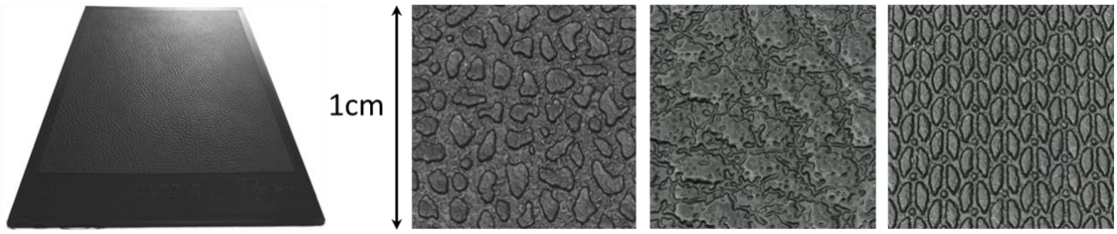

Figure 5. Example of test plate (21x15 cm) and microscopic view of texture 1 – 3 (from left to right)

The plastic surface textures were designed to provide a maximum leather-like appearance. The main question was to what extent the customers would be able to recognize the intended similarity. According to Figure 6, the textures exhibited a leather-like appearance to various degrees. Many test persons found a similarity to textile surfaces. Texture 2 shows the maximum leather-like appearance: 88% of the test persons selected images which express features of leather, whereas the haptic assessment scored 81%. Texture 2 thus proved to show a leather-like appearance in both modalities but needs more improvement to reduce the iconic features of textiles.

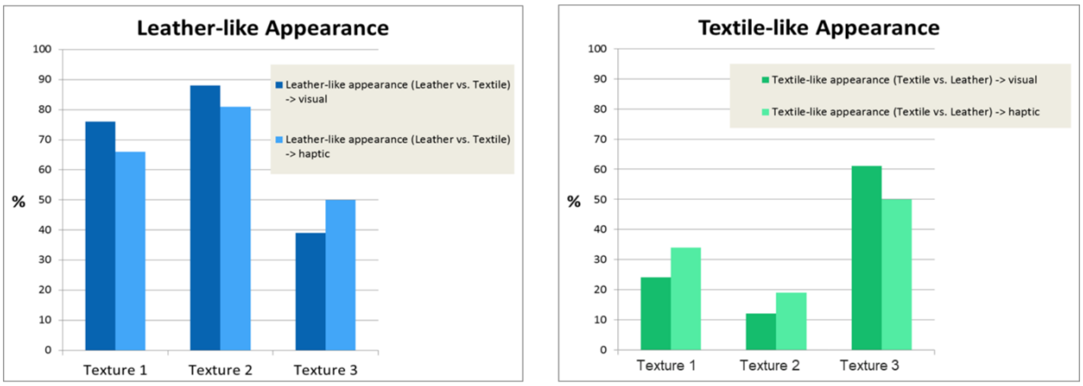

Figure 6. Result of image-based visual and haptic assessment: appearance of textures for the vehicle interior.

5. Conclusions

Iconicity, the associative content, is an essential feature of perceived sound. Therefore it is necessary to develop methods that are suitable to reliably assess the effect of such aspects in complex multisensory environments. A method that considers the complexity of daily life environments needs to exceed a pure verbal assessment by means of surveys, rating scales, and non-acoustic content for comparison. It is proposed to use manifold sets of images to achieve a detailed approach on individual effects and preferences. An image-based test procedure has shown great promise for multisensory assessment. Results from the assessment of automotive surfaces in the visual and haptic field indicate that it will also be advantageous in the case of sound assessment. Optimum conditions are provided with the evaluation of all relevant senses, like visual, tactile and auditory features. Furthermore, the benefit for olfactory analysis is also expected, based on the fact that iconic features count for the major effects of smell. Ideally, such a method incorporates a classical sensory analysis using rating scales and verbalizations. Selected images will be commented on by each test person. Further research needs to prove the method by including sound assessment into the multisensory task.

Acknowledgments

Many thanks to Jens Raabe and the experts at SenseEngineers/Köln for the sensory analysis. Furthermore, I would like to express my special thanks to Dr. Anja Moos and Nora Wolfsheim at Ford Werke GmbH Köln for their dedicated support for the method development and evaluation.

Additional information

The author declares no competing financial interests. The author owns the copyright for all figures except figure 4, for which the copyright has been granted by senseengineers / Köln (www.senseengineers.de).

References

1. M. Schafer; The tuning of the world; McCelland and Steward, Toronto, Canada, 1977.
2. ISO 12913-2:2018 Acoustics – Soundscape – Part 2: Data collection and reporting requirements; ISO, Geneva, 2014.
3. C. Spence; Crossmodal correspondences: A tutorial review; Atten Percept Psychophys, 2011, 73, 971–995. DOI 10.3758/s13414-010-0073-7.
4. M. Haverkamp; Synesthetic Design. Handbook for a Multisensory Approach; Birkhäuser, Basel, Switzerland, 2013.
5. M. Chion; Audio-Vision; Columbia University Press, New York, USA, 1994.
6. M. Haverkamp; Effects of Material Touch-Sounds on Perceived Quality of Surfaces; SAE World Congress WCX17, Detroit, USA, 2017, SAE Paper 2017-01-0495.
7. F. Aletta et al.; Soundscape assessment – Towards a validated translation of perceptual attributes in different languages; Proceedings of Internoise, 2020.
8. M. Haverkamp; Soft sounds in quiet cars – design with respect to subjective intensity of sounds; Proceedings of e-Forum Acusticum, 2020, 2377-84. DOI: 10.48465/fa.2020.0020
9. R. A. Kendall; Music and Video Iconicity – Theory and Experimental Design; J. Physiol. Anthropol. Appl. Human. Sci., 2005, 24(1), 143–49.
10. U. Jekosch; Assigning meaning to sound; In: Communication acoustics; J. Blauert (ed.), Springer, Berlin, Germany, 2005, 193–221.
11. W. Voss; Das Farbenhören bei Erblindeten; Psychologisch-Ästhetische Forschungsgesellschaft; Hamburg, 1930.
12. E. Özcan; R. van Egmond; Basic semantics of product sounds; International Journal of Design, 2012, 6(2), 41-54.
13. B. Flückiger; Sound Design – Die virtuelle Klangwelt des Films; Schüren, Marburg, 2, 2002.
14. M. Haverkamp; Beurteilung und Gestaltung von Geräuschen auf Basis inter-modaler Analogien; In: Subjektive Fahreindrücke sichtbar machen III. expert; K. Becker (ed.); Renningen, 2006.
15. M. Haverkamp; Advanced description of noise perception by analysis of cross-sensory interactions within soundscapes; Noise Control Eng. J., 2010, 58 (5), 540–50.
16. M. Masullo et al.; Preliminary qualification of a small audio-visual dataset for a multisensory study on urban parks; Proceedings of Internoise, 2020.
17. A. Radicchi; A Pocket Guide to Soundwalking – Some introductory notes on its origin, established methods and four experimental variations; In: Perspectives on Urban Economics; A. Besecke et al. (eds.); Universitätsverlag der TU Berlin, 2017, 70–73.
18. A. Gidlöf-Gunnarsson, E. Öhrström, M. Ögren; Noise annoyance and restoration in different courtyard settings - Laboratory experiments on audio-visual interactions; Proceedings of Internoise, 2007.
19. S. Basturk, L. Maffei, M. Masullo; Soundscape Approach for a holistic urban design; AESOP 26th Annual Congress, Ankara, METU, 2012.
20. senseengineers.de (24.6.2022)

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