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NOISE CONTROL FOR QUALITY OF LIFE

Core affect and soundscape assessment: fore- and background soundscape design for quality of life

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ABSTRACT

The first and foremost evolutionary role of audition is to estimate safety. One typical safety indicator is normalness and subcortical auditory processes are always estimating normalness. If the situation is normal and safe, our higher cortical functions are free to attend their own matters. But if subcortical and subconscious auditory processing are unable to estimate safety, they task cortical processes with vigilance tasks that arouse and make it more difficult to relax and to concentrate on self-selected activities. This is apparent from the way we appraise (sonic) environments and from the way these influence our moods (core affect). The words that we use to describe sonic environments reflect the difficulty to decide on appropriate behavior (easy in quiet environments and difficult in chaotic environments) and the affordance content (very low or inappropriate in boring environment and very high and highly appreciated in lively environments). The way arousal and attention is controlled is described in a recent model of sensory cognition that we summarize here. We conclude that it is not the physical attributes of sound, but the simplest – safety relevant – meaning attributable to the sonic environment that is the key to understanding soundscape quality. And this realization allows one to engage in soundscape design for quality of life. We end with a few suggestions to explicitly design for quality of life as alternative to design for compliance with noise regulations.

Keywords: soundscape, core affect, moods, quality of life, measurement, sensory cognition

1. INTRODUCTION

The theme of Internoise 2013 is “Noise Control for Quality of Life”. This article addresses this topic directly by providing a coherent theoretical framework from the domain of sensory cognition that connects ambient sound, sound appraisal, moods (core affect), and effects on long-term health and quality of life to sound design. This article starts with an outline of the role of audition and in particular the role of audible safety that is even for most acoustic professionals non-obvious. The words people use to describe sonic environments provide additional information about what (sonic) environments mean to people in psychological terms. This leads to the identification of four

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qualitatively different sonic environments – boring, chaotic, lively, and quiet – that differ in terms of complexity of behavior selection and affordance content. They also differ in terms of the role of foreground sounds (typically of somewhat distal intermittent activities) and background sounds (typically of a continuous nature, stemming from the proximal environment). These facets all play a role in a model of sensory cognition [1] that will be summarized in section 3. We end this article with a few suggestions to (learn to) design for quality of life instead of to design for compliance with noise limits.

1.1 The main role of sound in animals: estimating audible safety

Typically, research on sound perception has focused on speech, music, or meaningless computer generated stimuli. But the capacity to hear and listen – audition – has an evolutionary history of hundreds of millions years [2]; only very recently audition is used for speech, music, and beeps and as such these sounds have minimal evolutionary significance. In fact evidence suggest that initial phonetic abilities in children are identical to general animal abilities to structure complex sounds [3].

Hearing could evolve (i.e., provide adaptive benefits) because of a combination of two physical properties of sounds. In the first place, sounds are always produced when solids, fluids, or gasses interact [4]; all objects that hit each other or fluids and gasses that flow in irregular ways produce subtle or louder sounds. In the second place, sounds carry relatively far. In fact, compared to the size of the sound source, a sound may be audible at a distance of hundreds or thousands times the size of the source. The combination of these two properties entails that sounds inform about the presence of a multitude of (physical) activities in the near (rustling of leaves) and not so near (cars on a road) environment. In addition, it is generally very difficult to move completely silently; one little mistake and a predator may reveal its presence and intentions well before it has approached its prey sufficiently close. Warning functions are an important reason d'être for audition and it couples sound perception directly to safety.

Detecting potentially dangerous situations is not the only safety function of hearing: determining safety is just as important. It may even be more important because many more situations are safe than dangerous and if the safety of an environment can be estimated (heard) it allows an individual to relax or attend other matters than being vigilant in (potentially) dangerous situations. Audible safety indicators do not so much indicate safety, but normalness. And we (humans and probably other animals as well) like normal sounds. In fact it has been shown that the most pleasant sounds are also profoundly "normal" sounds [5]-[7]. We like the songs of birds, the sounds of quiet domesticated animals, children playing, the neighbor cleaning the house, the murmur of a quiet conversation on the street, and your child singing in the room. These are all sounds that match activities that we are engaged in exclusively when we feel safe. So a pleasant sonic environment is filled with the sounds of activities indicative of individuals (also of other animal species) who feel safe. And because all these indicators suggest pervasive safety, it is possible to engage in activities such as daydreaming and play in which we are minimally vigilant.

For millions of years, our ancestors have lived in natural environments that were, most of the time, filled with the sounds of these very normal activities. The auditory systems of all animal species have learned how and when to derive a justified sense of safety or insecurity from these sounds. However, as humans we have filled our lives with the sounds of non-natural origins. In fact where our distant ancestors only heard natural sounds, in our industrialized city and indoor environments days can go by in which we are not aware of a single natural sound. Even if natural sound sources such as birds or domestic animals are close by, they may be inaudible due to the masking effects of traffic, machines, ventilators, air conditioners, music, and closed windows. This may be interpreted as an impoverishment of the sonic environment in terms of what the auditory system evolved to do.

We have argued [1] that the decision of auditory safety is a (predominantly) subcortical process that is closely associated with the assignment of attentional resources. When a situation is deemed safe by subcortical processes, cortical functions are free to attend whatever they "see" fit. However, when the subcortical processes cannot positively estimate safety (or some form of normalcy), cortical resources remain vigilant to respond to the unexpected and potentially dangerous. We argued that this is the basis for sound annoyance. It is not necessary that a sound source has particular annoying sonic properties. The simple fact that a sound – pleasant or not – obscures more pleasant (safety-indicating) sounds is enough to be annoying. For example the sound of traffic is often not particularly unpleasant; it may even resemble the sound of the sea, which we typically like to hear. But traffic sounds mask the subtle sounds characteristic of local normalcy. As a result the main effect of the pervasive blanket of non-natural sounds that fill our cultural environments is to, further, disconnect us from our (natural) immediate environment. Unfortunately this entails that subcortical processes find it more difficult or even impossible to determine whether one is in a safe place. The predictable result is that we become more vigilant, more alert, and aroused. Consequently we are less likely to relax and/or engage in relaxing unforced activities such as play.

Since most of us do not feel unsafe most of the time, we presumably have learned to trust other (e.g., visual and in general cultural) indicators of safety; otherwise we would always be aroused. But maybe we are to some extend aroused, because what do we do when we want to relax? We take a stroll in a park. And that is not just a small and enjoyable digression; it is a very effective way to relax and restore the capacity for directed attention (which is important for work an problem solving in general) [8], [9]. This is an important observation because it shows that, although we have constructed a – by and large safe – environment with severely impoverished natural indicators of safety, we still seek natural environments for rest and relaxation.

1.2 Appraising sonic environments

The role of sound in life as described above is consistent with recent research in soundscape and emotion research that consistently [10]-[12] finds a construct called 'core affect' [13] to be associated with soundscape appraisal. Core affect is associated with moods: with our overall attitude towards the world. Compare to emotions moods are less specific and miss the intentionality (directedness to a particular state of affairs) that characterizes emotions. Appraisals refer not to states of the perceiver, but to states of the world that are relevant for a perceiver. We tend to use a broad variety of words to describe appraisals to the sonic or visual [10], [14] environment.

Research addressing how people appraise sonic environments has led to two main appraisal dimensions: either pleasure and eventfulness [10] or, at a 45 degree angle, vibrancy and calmness [11]. These combinations of dimensions are closely related to the concept of core affect in emotion theory. Core affect is an integral blend of the dimensions displeasure-pleasure (valence) and passive-active (arousal) [13]. Unlike emotional episodes, which are relatively infrequent, core affect is continually present to self-report. Recently, core affect, appraisal, and motivation have shown to be intimately coupled [15]. Figure 1 shows the close relationship between the basic structures of core affect and appraisal.

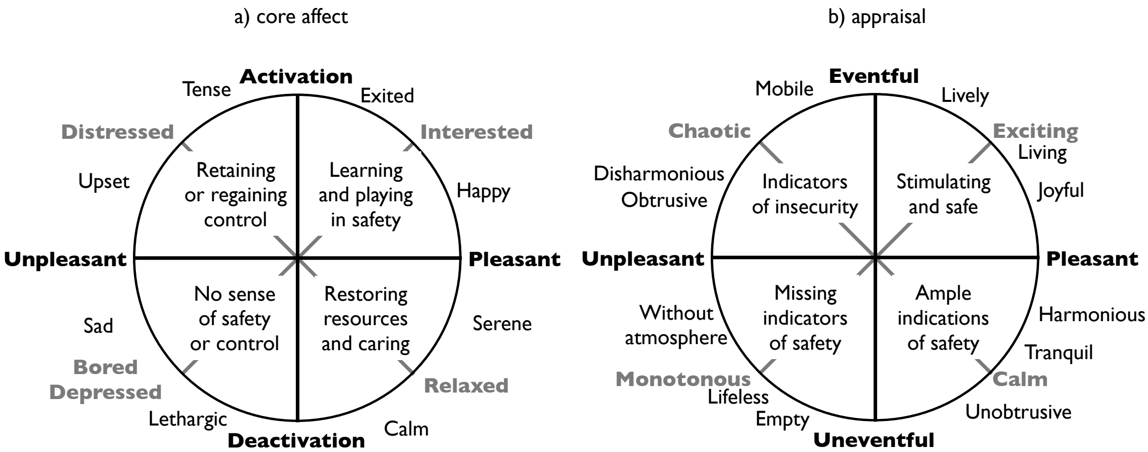

Figure 1. Basic dimensions of core affect (a) and appraisal (b).

Appraisals are "cognitive evaluations of events that are considered to be the proximal psychological determinants of emotional experience, with different combinations of appraisals corresponding to different emotions" [15]. Appraisals typically refer to: motivational relevance ("Is it important?"); motivational congruence ("Is it advantageous or disadvantageous?"); agency ("Is it caused by others or myself?"); problem and emotion focused coping potential ("Can I cope with the situation and with my emotions?"); future expectancy ("Is the expected outcome desired or not?"). Appraising the environment therefore combines motivation, coping capacity, and expectations of the future. As such the appraisal process involves the evaluation of possible (inter)actions with the environment.

Depending on the outcome of these evaluations we are motivated to initiate, continue, or discontinue particular courses of action. It is possible to separate extrinsically and intrinsically motivated activities. Extrinsically motivated activities are aimed at reactively coping with acute or future problems and have fear as associated basic emotion. Intrinsically motivated activities allow proactive (e.g., preventive) coping and the discovery of affordances [16] and have interested as associated basic emotion.

The term affordance is closely related to the appraisal process. Affordances are perceived action possibilities that might be used to satisfy (immediate or future) needs. Interest driven interaction extends the capacity to perceive affordances. For example Silva [17] concludes that "*by motivating people to learn for its own sake, interest ensures that people will develop a broad set of knowledge, skills, and experience. One never knows when some new piece of knowledge, new experience, or new friendship may be helpful; interest is thus a counterweight to feelings of uncertainty and anxiety.*" Interesting environments provide discoverable affordances to extend knowledge and skills through typically playful interaction. Boring environments are devoid of discoverable affordances and do not provide appreciated novelty (e.g., because they are devoid of stimuli, or the stimuli are ether too ordered to maintain interest or too complex to determine constituting structure).

The complexity of an environment is, in this context, a reference to how difficult it is to cope with the challenges the environment provides. Low complexity environments are highly redundant (each part "predicts" the whole, which leads to an impression of harmony) and action outcomes are insensitive to behavior detail. High complexity environments are less redundant (leading to a lack of internal coherence and an impression of chaos or confusion) and action outcomes are highly sensitive to behavioral detail.

This interpretation is supported by an analysis (derived from the New Oxford Dictionary) of 16 words [10] typically used in appraising sonic environments (see Figure 1b). These descriptions, presented in Table 1, support the key role of affordances and complexity.

Table 1. Dictionary descriptions of words commonly used in appraising sonic environments.

High complexity Forced search for best behavioral option **Chaotic:** in a state of complete confusion and disorder **Mobile:** able to move or be moved freely or easily **Disharmonious:** lack of harmony or agreement **Obtrusive:** noticeable or prominent in an unwelcome or intrusive way	**High on affordances** Enjoying opportunities **Exciting:** causing intense and eager enjoyment, interest, or approval to do or to have something **Joyful:** feeling, expressing, or causing great pleasure and happiness **Living:** have an exciting or fulfilling life **Lively:** (of a place) full of activity and excitement, (of mental activities) intellectually stimulating or perceptive
Low on affordances Searching for affordances **Monotonous:** dull, tedious, and repetitious; lacking in variety and interest **Without atmosphere:** a place or situation without a pervading tone or mood **Empty:** containing nothing; not filled or occupied **Lifeless:** lacking vigor, vitality, or excitement	**Low complexity** Freedom of mind-states **Calm:** the absence of violent or confrontational activity within a place or group **Unobtrusive:** not conspicuous or attracting attention **Tranquil:** free from disturbance **Harmonious**: forming a pleasing or consistent whole.

1.3 Four types of sonic environments

This analysis suggests four qualitatively different types of sonic environments in terms of the complexity of action selection and affordance content [18]. The complexity of an environment depends on the prevalence and reliability of indicators of safety. Highly complex or chaotic environments are difficult to interpret (e.g., due to an overabundance of sound producing activities) or actively indicative of danger. A boring sonic environment is low on useful audible affordances and is also not indicative of safety. In contrast, a lively environment represents many affordances that provide ample interesting opportunities to attract attention and is not indicative of danger. The fourth environment is a calm or relaxing one because it provides ample indications of safety and allows, as such, full freedom to relax and recuperate. Figure 2 provides these four domains of soundscape appraisal (text on the left and right) and the associated quadrants of core affect.

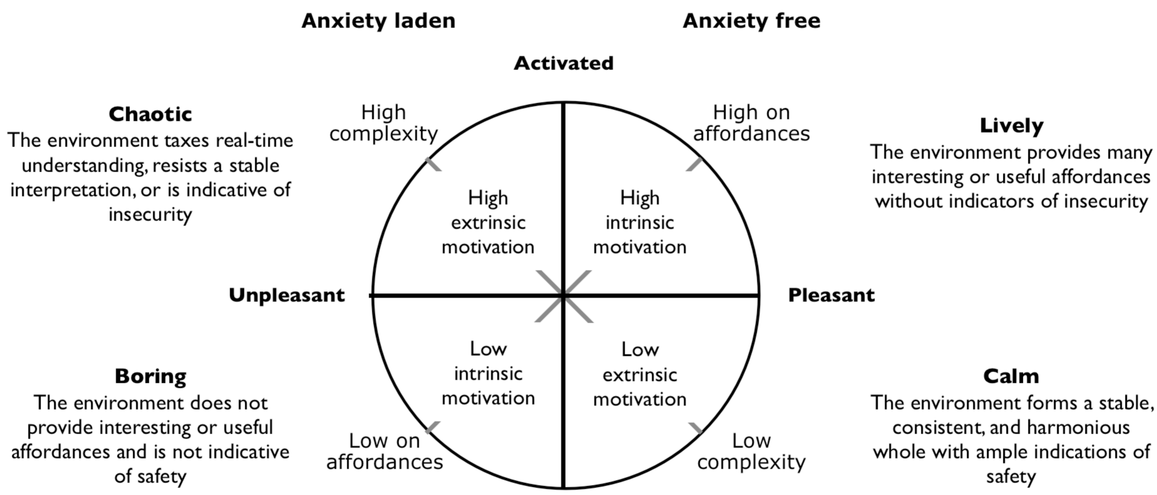

Figure 2. Four types of sonic environments connected to core affect

1.4 Foreground and background

These four types of environments can be connected to results regarding noise sensitivity. Job [19] concludes that *"results consistently show that, despite ubiquitous reference to noise sensitivity as a single entity in the literature, in fact noise sensitivity is not a unitary concept. Rather, it generally contains two distinct factors: sensitivity to loud noises produced at a distance from the hearer (e.g., road traffic or jackhammer noise), and sensitivity to situations of distraction or close but quieter noises (e.g., rustling paper at the movies, people talking while watching television)"*. Sensitivity to noise therefore comprises both distal and proximal situational awareness as distinct components.

Distal situational awareness is predominantly determined by the loudest (foreground) sound events and proximal situational awareness by the subtle (background) sounds. This suggests a matching fourfold separation in pleasant and unpleasant fore- and background. This distinction is not in the first place based on signal properties, but on the assignment of attention. The assignment of attention is an emerging property of the interaction between the agent, its (safety) needs, and the environment. It cannot be estimated in full from signal properties, but must take agency – the capacity to self-initiate activities and to self-assign meaning or irrelevance – into account.

The foreground is very salient and as such attended, while the background, although processed up to a certain degree, is not very salient and not usually attended. Saliency in this context is typically defined in terms of safety indicators, but also in other behaviorally relevant stimuli, such as your name. Another important difference between fore- and background is that the background is always present, although it might not always be audible because it can be masked temporarily by foreground sounds. The foreground, when present, is always attended and therefore audible. The background, when audible, consists of the sounds that characterize the overall properties of the environment and provides a continual sense of place. Background processing does not require conscious attention to provide, continually, information about where one is and if all is still normal and safe. In contrast the foreground is strongly related to the events that occur in the environment and provides information about the main events that happen.

An unpleasant foreground is experienced as chaos and either difficult to understand in real-time or outright indicative of danger and as such highly arousing. An unpleasant background is boring and devoid of indicators of safety or positive affordances, it is mildly arousing because it activates a futile and frustrating search for (absent) audible safety. A pleasant foreground is lively and full of appreciated affordances. It is also arousing, but in this case the arousal is self-selected and under agentic control. Finally, a pleasant background is relaxing due to the harmonious (and therefore redundant) nature of the sonic environment that provides – for that reason – ample indications of safety (conform [1]). Figure 3 summarizes the appraisal of the sonic environment in terms of a pleasant and unpleasant fore-and backgrounds, in combinations with the effect of appraisal quadrants on arousal and mind-states. Note that these, in principle, can be used for designs that are conducive for particular mind-states.

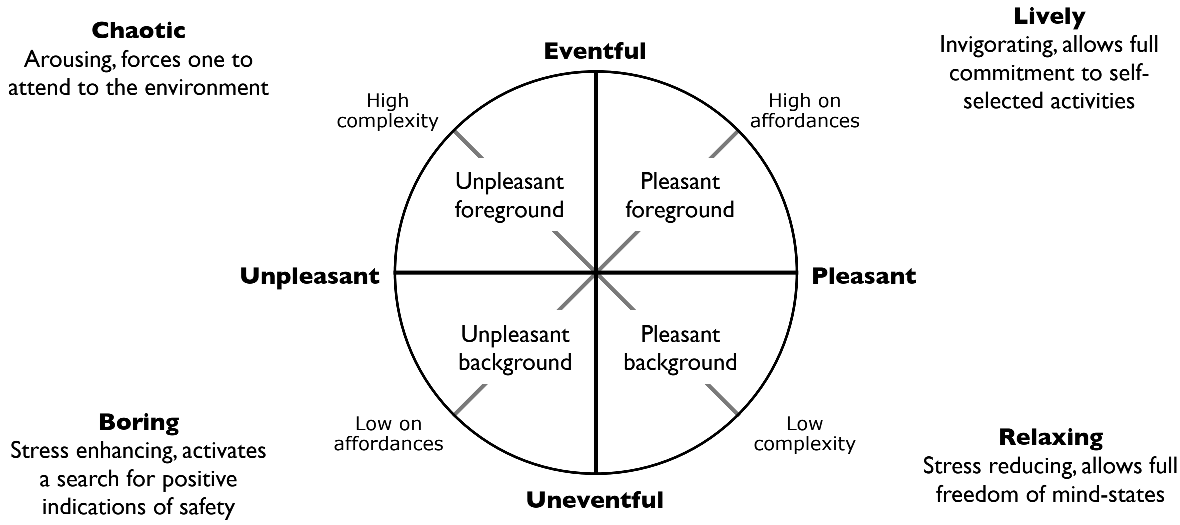

Figure 3. Appraisal as foreground-background separation and effects on mind-states.

Table 3 provides an overview of the (functional) differences between fore- and background sounds, that elucidate their quite different role and match with the two forms of noise sensitivity that Job [19] identified. Also de Coensel and Botteldooren [6] noted that *"a feeling of quietness is determined by intervals of silence where silence itself is defined as the ambiance of a soundscape, the gap or distance, the auditory space between sound events"*, which is also suggestive of the quite different roles of foreground sounds (sonic events) and background sounds (ambiance).

Table 2. Typical properties of background and foreground sounds

Background sounds – ambiance	**Foreground sounds – events**
Indicative of ambiance	Indicative of (often more distal) sonic events
Usually not attended	Always attended when present
Always present	Not always present
Not perceivable if masked by foreground	Always audible when present
Main basis for proximal situational awareness	Main source of distal situational awareness
Predictable from context, generally highly redundant: the parts predict the whole. Not very salient	(In part) not predictable from context (requiting attentive processing). The less predictable the more salient.
Poor quality if devoid of indications of safety (absence of positive affordances)	Poor quality if indicative of chaos or when masking more pleasurable background sounds
Good quality if harmonic (redundant + safe) and indicative of pervasive safety	Good quality if indicative of activities consistent with proactive need satisfaction. Abundant positive affordances.
Positive examples: quiet natural sounds, quiet human or animal activities, soft endorsed music	Positive examples: sound of self-selected activities, humans engaged in safety indicating activities, endorsed (life) music
Negative examples: sound of (constant) traffic, ventilators, machines	Negative examples: passing vehicles (especially scooters), loud not endorsed music, sound of arguing neighbors

2. Sensory Cognition model

For those that do not want to be bogged down by too much psychology, this section can be skipped, but it is useful to know about the main functional aspects of sensory cognition to understand how environments are appraised (i.e., initial meaning is attributed to environmental stimuli). Recently we [1] proposed a cognitive model describing what we term core cognition, which explains the patterns of experimental and phenomenological observations of soundscapes. This model assumes that core cognition prioritizes needs and regulates arousal (i.e., allocation of mental and physical resources to tasks). These two functions match the diagonals of the core affect diagram, as depicted in Figure 4. Need priorities are associated with the lower left to upper right diagonal that reflects whether the environmental affordances match existing needs. The matching arousal level is associated with the question of how difficult it is to select appropriate behavior. These correspond to a progression of mind-states from maximally restoring, in situations in which behavior selection is very easy, to inefficient and (highly) effortful in situations that are too complex to cope with. These mind-states are also depicted in the middle column of Figure 5.

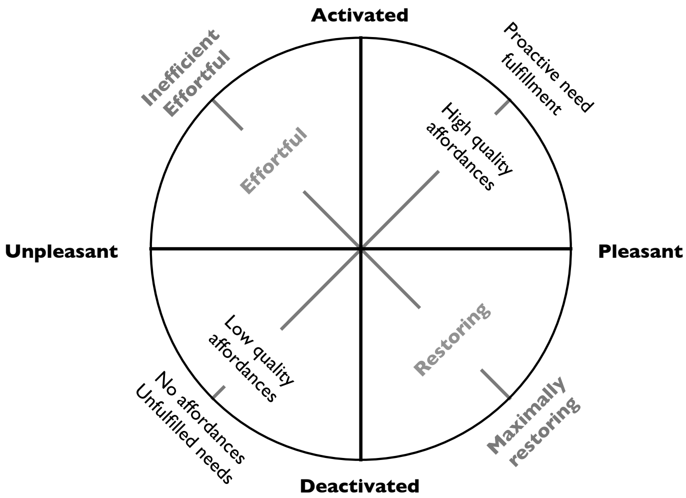

Figure 4. Core affect in terms of complexity of behavior selection and affordance content. The upper-left to lower-right diagonal corresponds to the middle column and to arousal in Figure 5.

Figure 5, although seemingly complex, has only three main components: core cognition, (cortical) mind-states, and peripheral sensing. The block on the right side depicts the different peripheral sense modalities that are, via the two lower connecting routes, interpreted superficially by the oval denoted as core cognition. Signal stimuli presented via this route are used for tuning arousal, need prioritizing, and mental task activation. Alternatively, sensory stimulation can be interpreted in more detail with the diverse mind-states of conscious processing, which are represented as four dotted boxes in the middle. These reflect a continuum of mind-states that, with increasing arousal, are more constrained by core cognition. The lowest mind-state corresponds to sleep and dreaming as minimal forms of conscious awareness. The second box corresponds to attention capturing by the input in combination with perception-action automatisms, termed direct perception [20], which are typical for perceptual fascination and "automated" activities like walking. The third and fourth boxes reflect directed attentional states. The fourth state involves effortful switching between proactive and reactive tasks, which is apparent if one is unable to ignore an irrelevant but annoying sound. In its extreme it corresponds to a complete domination by a sound source or other environmental stimulus. The words in bold denote the restorative or effortful quality of the different mind-states that are also reflected in Figure 4. The connecting arrows between the mind-states and peripheral sensing suggest progressively more focused attentional states at higher arousal. The highest arousal level is characterized by forced task switching between self-selected task-consistent (proactive) and distractor-consistent (reactive) foci of attention.

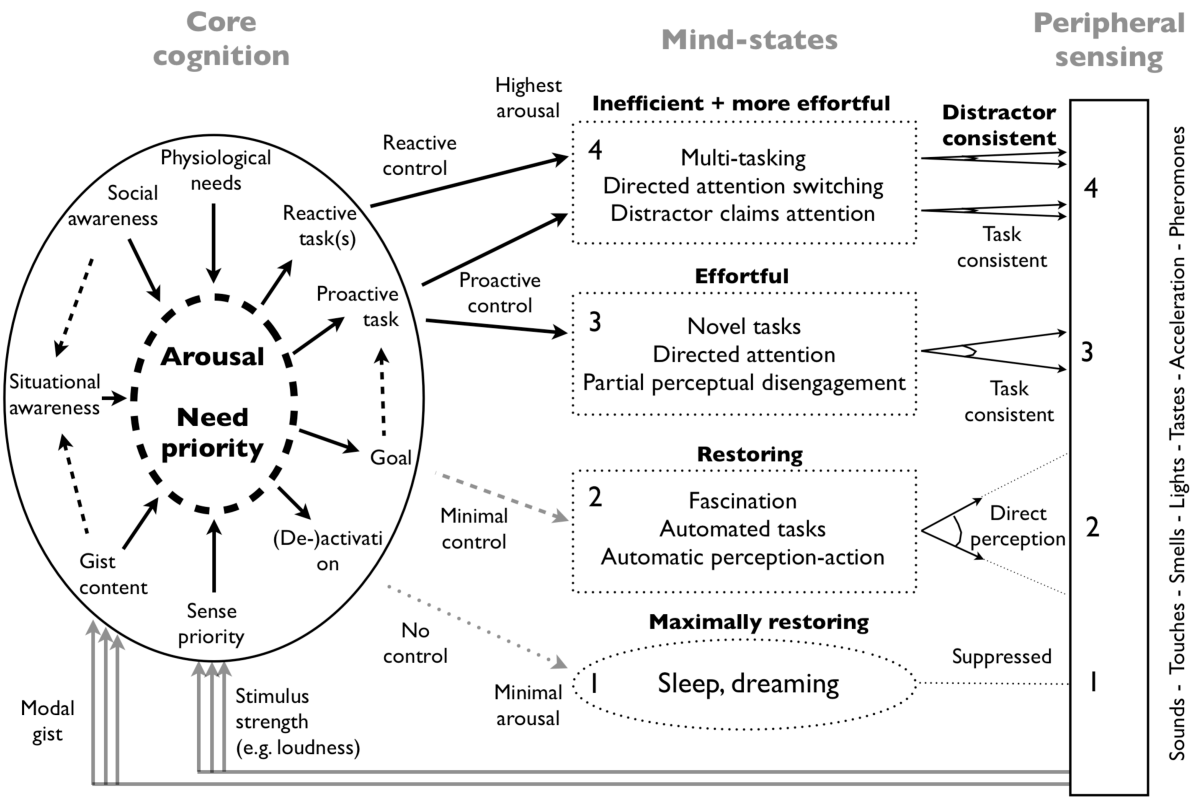

Figure 5. Model of the different processes involved in (sound) annoyance. The middle column corresponds to the upper-left to lower-right column in figure 4.

The box termed 'core cognition' on the left describes the subconscious and subcortical processes that constrain conscious mind-states (the middle column) to various degrees depending on current needs and a crude analysis of peripheral processing. Needs, such as the need for food or the need to pee, develop throughout the day and can be addressed proactively if the situation allows it, or reactively, when the need becomes so important that it can no longer be ignored. Satisfying a neglected need becomes the dominant task of the whole mind/brain and is indicative of unsuccessful proactive need satisfaction. Social awareness is also a function of core cognition because we use the situational awareness of other agents (humans or animals), as apparent from their audible and otherwise perceivable activities, to augment our own sense of vigilance. This forms the psychological basis why pleasurable sounds are often so profoundly normal.

The crude perceptual analysis of core cognition occurs via two signal routes. One route depends predominantly on signal strength, such as a loud sound or a stench, which motivates the perceiver to attend to the environment consciously to address potential danger (denoted as a 'reactive task'). The other route, indicated as 'modal gist', corresponds to a more detailed analysis in which signal expectations are compared with the actual input. Expectations that match the actual stimulus statistics typically indicate normalness and safety and allow cortical mind-states freedom to decide their own content or to address proactive (self-selected) tasks. Violations of expectations or particularly well-trained stimuli (such as your name) or obnoxious stimuli (such as the sound of puking or nails on a blackboard) lead, like the activation of the signal strength route, to the activation of a reactive task to actively cope with the environment.

To summarize: if core cognition is not positively assured of safety, it tasks the cortical workspace, through arousal, with the responsibility to (re)assure safety or, at minimum, be vigilant. This is beneficial since an aroused animal or human is: (i) more responsive to sensory stimuli in all modalities; (ii) more active motorically; and (iii) more reactive emotionally [21]. As such it allows the agent to respond adaptively to the here-and-now.

3. Sound design for quality of life

The emerging framework based on the acknowledgement that it is not the physical attributes of sound, but the simplest – safety relevant – meaning attributable to the sonic environment that is the key to understanding soundscape quality, allows one to engage in soundscape design for quality of life. The question now is not how can we design for a quiet house, or even a house with a quiet façade, but how can we design for a diversity of mind-states and need satisfaction that allow for the adoption of healthy habits and lifestyles [22]. There is no magic bullet to solve soundscape problems and to design and maintain ideal sound- and sensescapes (the generalization of soundscape over all sensory modalities).

A good city sensescape balances the needs of the whole community while respecting the needs of all individuals and is therefore always the outcome of local optimization and not of centrally enforced regulations (although these may play a facilitating role). A good sensescape provides a broad diversity of opportunities for individuals to remain healthy and happy. Where noise-legislation based design effectively promotes uniformity, designing for quality of life involves the creative use of local opportunities, citizen needs, and cultural preferences to promote a well-chosen diversity of (sonic) environments.

In this framework it is possible to design for particular and predictable psychological effects. In fact it may be possible that the repertoire of the acoustical consultant to reduce sound annoyance and to improve quality of life is much larger than current practice suggests. Examples include the following.

- *Design for easiness to ignore annoying sounds.* Our research indicates [23] that being reminded by an annoying sound is the main reason of its annoyance. In particular people complained because its constant, frequent, or unpredictable presence or because it had particular source properties. Loudness, although important, was not much more reported than the other factors. This suggests that more subtle interventions that address the attention attracting properties might often be possible. For example, reducing the high frequency content of a sound source may be relatively cheap and it may reduce its attention gabbing qualities. At the same time it may make local bird sounds more audible and in doing so shift the appraisal of the sonic environment towards the lower right. The loudness effect of this intervention may be small, while its well-being effect may be important.
- *Designing for audible safety*. Courtyards, parks, and other spaces that are now quiet and boring can be enriched by a variety of safety indicating sounds that are indicative of animals and humans activities only executed in safety. The barely audible effect of a reader turning the page of a book or an animal scurrying through some leaves can have a profound effect on experienced audible safety and may change a very quiet and somewhat boring environment in a relaxing one. The same holds for subtle water or wind features or the audible presence of domesticated animals and birds.
- *Simply choosing for the quietest options and structurally replacing louder apparatuses with quieter ones* (conform the http://noiseabatementsociety.com/quiet-mark/). This allows people to experience the subtle and reassuring sounds of the environment more, which reduces arousal.

Much of this is already known from acoustic experience, but it is usually not coupled to sensory cognition research. The combination of the experience of urban planners, acoustic consultants, soundscape experts, and knowledge of sensory cognition will lead to more effective approaches to existing problems, and even more importantly, to the prevention of health problems by providing a broad diversity of environments that allow the citizenry to self-regulate mind-states according to needs. However to further enhance our understanding it would be highly beneficial to analyze why communities and individuals in acoustic environments that are similar in terms of L_{den} differ so much in subjective well-being.

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