Thesis for the degree of Doctor of Philosophy

Emotional Influences on Auditory Perception and Attention

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Abstract

The auditory perception is a fundamental part of our interactions with and experience of the external environment. We receive considerable amount of information from our surroundings through sounds. The auditory system takes care of this continuous flow of information in a seemingly effortless manner. It functions as an adaptive and cognitive alarm system that scans our surroundings, detects and analyzes the significant events, and signals for attention shifts to objects of interest. The research presented in this thesis focuses on the influence of emotions on the perception of sounds, and proposes that the affective experience is integral to the auditory perception. In particular, the current research explored how the affective qualities of auditory stimuli may modulate the way we attend to and perceive the sounds around us.

In Paper I, employing an affective learning paradigm, the author investigated whether the learned emotional meaning of an otherwise meaningless sound could influence the perception of a basic auditory feature: loudness. The main focus of Papers II and III was on the emotional modulations of spatial auditory perception. Paper II presents a study that set out to investigate whether the affective quality of sounds can provide exogenous cues of the orientation of spatial attention. Paper III concerns the potential of the auditory spatial information to possess emotional value and modulate attention. Finally, in Paper IV, the authors investigated the importance of the emotional information for the auditory perception in the presence of a complex environment with a number of concurrent sounds.

Overall, it was found that both the loudness perception and the spatial auditory perception can be modulated by emotional significance, and that auditory-induced emotion is constructed using the available information in the auditory stimuli involving the spatial dimension. Further, the current research provided evidence that the emotional salience provides cues for the allocation of attention in the auditory modality.

Taken together, the current research set out to investigate the influence of the emotional salience on auditory perception. Perception is our everyday tool to navigate our surrounding world; and the finding that emotions can modulate the way we perceive our surroundings may help to improve the quality of everyday environments that we all occupy.

Keywords: auditory perception, attention, emotion, auditory-induced emotion, core affect, auditory spatial attention, change deafness, dot-probe, conditioning

List of publications

This thesis is based on the work contained in the following appended papers, referred to by their Roman numerals in the text:

Paper I

Perception of loudness is influenced by emotion.

E. Asutay and D. Västfjäll

PLoS ONE, **7**, e.38660, 2012. doi: 10.1037/journal.pone.0038660

Paper II

Negative emotion provides cues for orientation of the auditory spatial attention.

E. Asutay and D. Västfjäll

Submitted to *Frontiers in Psychology*

Paper III

Attentional and emotional prioritization of the sounds occurring outside the visual field.

E. Asutay and D. Västfjäll

Submitted to *Emotion*

Paper IV

Emotional bias in change-deafness in multisource auditory environments.

E. Asutay and D. Västfjäll

Journal of Experimental Psychology: General, **143**, 27-32, 2014. doi: 10.1037/a0032791.

The following publications are not appended to the thesis due to an overlap of contents or the contents going beyond the scope of this thesis:

1. Asutay, E. & Västfjäll, D. (2013). Change detection in complex environments is influenced by emotion. *International Society for Research on Emotion 2013 (ISRE 2013)*. Berkeley, CA, USA.
2. Asutay, E. (2013). Physical measurements and subjective characterization of pipe organ mechanical key actions. Licenciate thesis, Chalmers University of Technology, Sweden.
3. Asutay, E., Västfjäll, D., Tajadura-Jiménez, A., Genell, A., Bergman, P., & Kleiner, M. (2012). Emoacoustics: A study of the psychoacoustical and psychological dimensions of emotional sound design. *Journal of the Audio Engineering Society,* **60**, 21-28.
4. Asutay, E., Kleiner, M., & Västfjäll, D. (2012). Development of methodology for documentation of key action properties and haptic sensation of pipe organ playing. *Acoustics Bulletin*, **37**, 42-44.
5. Asutay, E. (2011). Development of methodology for documenting the organ sound and dynamic behavior of key action. *Organ Conference 2011*, Bremen, Germany.
6. Asutay, E., Kleiner, M., & Västfjäll, D. (2010). Haptic sensation in organ playing. *Haptic and Audio Interaction Design 2010 (HAID2010)*, Copenhagen, Denmark.
7. Asutay, E., Västfjäll, D., Tajadura-Jiménez, A., Genell, A., Bergman, P., & Kleiner, M. (2010). Emoacoustics. *Perceptual Quality of Systems (PQS 2010)*, Bautzen, Germany.
8. Tajadura-Jiménez, A. Väljamäe, A., Asutay, E., & Västfjäll, D. (2010). Embodied auditory perception: The emotional impact of approaching and receding sound sources. *Emotion*, **10**, 216-229.
9. Bergman, P., Västfjäll, D., Asutay, E., Tajadura-Jiménez, A., Sköld, A., Genell, A., & Fransson, N. (2008). Emoacoustics: Sound character versus source meaning in emotional responses to sounds. *Proc. 9th International Congress on Noise as a Public Health Problem.* Foxwoods, CT, USA.
10. Västfjäll, D., Asutay, E., Genell, A., & Tajadura-Jiménez, A. (2008). Form and content in emotional reactions to sounds. *Journal of the Acoustical Society of America*, **123**, 3245 (Abstract). Presentation at Acoustics 08, Paris, France.

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Contents

1. Introduction

"Sound is intrinsically and unignorably relational: it emanates, propagates, communicates, vibrates, and agitates; it leaves a body and enters others; it binds and unhinges, harmonizes and traumatizes; it sends the body moving, the mind dreaming, the air oscillating. It seemingly eludes definition while having profound effect." (LaBelle, 2007; p. ix)

During the process of writing this introductory chapter for the current thesis I wanted to point to, rather strongly, the concept that sound and perception of sound are multifaceted phenomena. The quote from LaBelle (2007) perfectly states what I had in mind. Sound underlies most communication: we talk to people and listen to what they have to say, we listen to music both to relax and to blow off steam, we even communicate via sound with our pets. Apart from that, we receive a vast amount of information through sound, about the objects, events and spaces that surround us. Parts of this complex input interest us while the rest may go unnoticed. We possess a remarkable ability to decompose the auditory input into separate channels of information, and focus on the ones we prefer and push the others in the background (Bregman, 1999; Fritz, Elhilali, David, Shamma, 2007; Shinn-Cunnigham, 2008). In the following chapters these mechanisms are discussed in more detail. Higher-order processes like attention, motivation and prior experience has a tremendous influence on sound perception (e.g. Snyder, Gregg, Weintraub, & Alain, 2012; Weinberger, 2010). The current volume concerns the influence of emotions on perception of sound, and proposes that affective experience is integral to auditory perception.

First, we need to consider emotions in the context of sound perception. As the quote at the beginning of the chapter beautifully illustrates sound moves, harmonizes and traumatizes us. Sounds have a great potential to carry biologically significant, emotional information, such as infant cries, laughter, and other emotional conspecific vocalizations (Altenmüller, Schmidt, & Zimmermann, 2013). Research shows that sound evokes emotions in people due to its affective quality (see; Tajadura-Jiménez, 2008). Further, the auditory system detects and identifies significant objects and events around us, and orients the attentional system to a particular region of interest (Arnott & Alain, 2011). Importantly, it integrates the behavioral state (attention, motivation, and action) of the organism to its processing (Weinberger, 2010). Emotions, on the other hand, work in concert with the perception during the processing of sensory information (de Gelder & Vroomen, 2000). They help us establish our motivation and preferences about certain places, people or things surrounding us (Lang & Bradley, 2010); and they can call for quick mobilization for action if necessary (Frijda, 2008). Neuroscience research over the recent years has pointed out that affective processes influence not only attention and sensory processing but also other high-order processes like learning and memory (Phelps, 2006). The current thesis investigates how and why emotional processing modulates auditory perception and attention. Thus, the broad question of interest is:

How does the affective quality of auditory stimuli modulate the way we attend to and perceive sounds?

Evidently, this is a broad question, and the current thesis does not claim to come up with an ultimate answer to it. However, it presents research designed for investigating the particular topic. In order to provide answers, the research presented here concerns more narrow research questions (see Chapter 6). The appended papers (Paper I-IV) present the experiments that were carried out in order to investigate the research questions. In Paper I, an affective learning paradigm was employed to study the influence of emotional processing on the perception of a basic auditory feature: loudness. Papers II and III presents experiments carried out where the focus was on the spatial dimension of sound perception. I investigated whether emotional salience of sounds can provide exogenous cues for orientation of spatial attention in Paper II, whereas Paper III concerns the potential of auditory spatial information to possess emotional value and modulate attention. Finally, in Paper IV, I set out to investigate the importance of emotional processing on auditory perception while the participants were exposed to a complex environment with a number of concurrent sound sources.

1.1 Organization of the Present Thesis

The current volume consists of seven chapters with the aim of providing theoretical and methodological framework to answer the research questions and for the appended Papers I – IV. Chapters 2 – 4 form the theoretical framework. Chapter 2 presents a brief review of contemporary emotion theories and their views of what emotions are. It also introduces the concept of core affect, which is a key concept for this thesis. The chapter ends with a section on the role of emotions in auditory perception and how sounds can evoke emotions in listeners by modulating their core affect. Chapter 3 introduces the basic properties of auditory perception and attention. It first focuses on the auditory system physiology and the perception of sounds, and then, discusses the concept of auditory attention and its role in perception. Overall, Chapter 3 presents a view of the auditory system as an adaptive and cognitive network specializing in processing acoustic stimulus features and integrating those with the attentional and motivational state of the organism. After the chapters focusing on emotions and perception separately, Chapter 4 provides a review on how and why emotions influence attention and perception, drawing mostly from the evidence in visual domain. Chapter 5 presents the research methodology employed in the appended papers. In particular, it describes the approach for studying the auditory-induced emotions and summarizes emotion and attention measures. In Chapter 6, specific research questions of the current thesis and a summary of the appended papers are presented. Finally, in Chapter 7 the findings of the appended papers are discussed in the light of the research questions and their contribution to several research areas.

2. Emotions

"… *few writers have failed to compare emotion as described by psychologists with the elephant as described by blind men in an old fable.*" (Russell, 2003; p. 145)

What is an emotion? William James (1884) asked this question over a century ago, probably hoping to give an answer. When you ask this question nowadays it is highly probable that you would receive as many different answers as the number of scientists carrying out emotion research. Theorists are far from reaching an agreement on the definition of the concept of emotion. Some of main considerations are: whether emotions are biologically fixed modules or psychologically constructed concepts; whether there are discrete emotion categories or emotions form a continuous spectrum; whether they occur precognitive or postcognitive; and whether there is a specific start and an end to an emotional episode. As one can see, these questions are not trivial when the scientific task is to explain the concept of emotion.

In this chapter, I briefly present a review of some of the main contemporary emotion theories and their understandings of what emotions are. Then, I introduce the concept of the core affect and its properties; and I argue that it is a basic property of the emotional experience. I end the chapter with a section on the role of emotions in auditory perception, and how sounds can induce emotions by modulating the core affect.

2.1 Emotion Theories

Theorists carrying out emotion research usually try to define what an emotion is using the components they consider as part of an emotional experience. Different theories include different components in their models. Some of those components are cognitive (appraisals), motivational (approach vs. avoidance) and/or embodied (somatic and/or motor components) in nature (Moors, 2010). Further, they all try to address the questions posed above and to demarcate emotions from non-emotions. Since the late 20th century, there are three main approaches to emotional experience: (1) basic emotions view, (2) appraisal models and (3) psychological constructionist models.

2.1.1 Basic Emotions

Basic emotion theories are built on the premise that there are a number of emotion categories that are psychologically and biologically fundamental states; that is, the building blocks of emotional life (Ekman, 1992; Izard, 1977; 2007; Panksepp, 2007). According to Ekman (1992) there are six basic emotion categories: anger, fear, disgust, happiness, sadness and surprise. These categories are universal; exist in nature with clear boundaries; and have clear physiological and behavioral manifestations that can be identified. The basic emotion categories are fixed biological modules, creating the idea that these emotion categories are "natural kinds" from a philosophical perspective. This means that emotions are fundamental states that cannot be broken down into more basic components. In other terms, a specific event (e.g. encountering a wild animal) can trigger a specific biological emotion module (e.g. fear) that would produce unique physiological response patterns (e.g. elevated heart rate), facial expressions (e.g. wide, unblinking eyes), and behavioral effects (e.g. freezing) characteristic to that particular emotion category (Figure 2.1).

Even though this view of emotion intuitively makes sense, the research on affective neuroscience growingly challenges the basic emotion theories (e.g. Barrett, 2006a; Barrett et al., 2007a; Russell, 2003; Lindquist, 2013). Recent evidence suggests that the basic emotion categories fail to consistently produce specific physiological response patterns, facial or vocal expressions (Mauss & Robinson, 2009; Russell, Bachorowski & Fernández-Dols, 2003; Barrett, 2006a); and that specific emotions are not associated to specific neural circuits or functional brain activity (LeDoux,

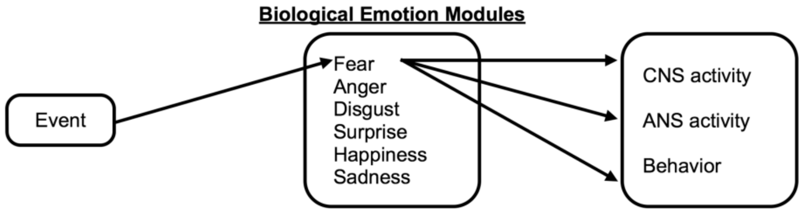

Figure 2.1 The diagram depicts a simplified schematic view of the basic emotion approach. An event triggers one of the specific biological emotion modules (fear in the diagram), which would lead to unique physiological response patterns (both ANS and CNS) and facial, vocal and motor responses. In this case a fear module would lead to elevated heart rate, wide unblinking eyes, cracking of the voice and freezing/fleeing.

2012; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). The data suggests that other psychological processes like semantic knowledge and memory are involved in the emotional experience.

2.1.2 Appraisal models

According to the appraisal models, events and objects do not trigger emotions in a reflexive and consistent pattern. Instead emotions are formed by a meaningful interpretation of events by the individual. In other words, the appraisal theorists suggest that a cognitive component or process comes before and is a part of the emotional experience. Hence, first a cognitive appraisal of the situation makes meaning of the event and the context, which in turn induces the emotion. The term appraisal refers to the cognitive processes that are involved in emotion induction, and is coined by Arnold (1960), whose work inspired the appraisal models of emotion (e.g. Lazarus, 1991; Frijda, 1986; Scherer, 2009a; 2009b).

In appraisal models, it is the cognitive component (i.e. appraisals) that determines which stimulus leads to emotion, what kind of emotion is evoked and how intense it is (Moors, 2010). Appraisals also come before and largely determine the bodily responses to an emotion eliciting stimulus. A recent influential model (Component Process Model; CPM, Figure 2.2) by Scherer (2009a, 2009b) suggests that a stimulus or an event and its consequences are appraised according to a set of criteria such as relevance, significance, and coping potential. The result of the appraisal modifies the motivational state of the individual (e.g. approach or avoidance); and both the appraisal results and the motivational changes lead to the modulations

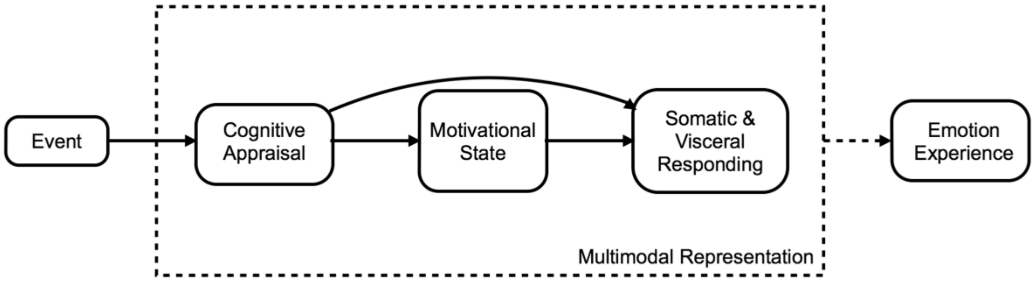

Figure 2.2 A schematic view of the Component Process Model (Scherer, 2009a; 2009b) is depicted in the figure. An event and its consequences are appraised according to a set of criteria. The appraisal results modify the motivational state of the individual, and both the motivational changes and the appraisal results lead to changes in the autonomic and somatic nervous system responding. All these components are integrated and represented in the brain that forms the emotional experience.

in the autonomic and somatic nervous system (ANS and SNS) responding. These modulations are somatovisceral changes and facial, vocal and bodily expressions. All these components (the appraisal results, the motivational state and the bodily influences) are represented and integrated in the brain. Then, this multimodal representation that forms the emotional experience is labeled by the individual using the emotion categories.

The appraisal theories have come up with a number of appraisal criteria or variables, each of which describes a certain aspect of the encounter between the event and the individual. Appraisal results from each variable form an appraisal pattern, which in turn leads to an emotional episode. Some of the suggested criteria (Scherer, 2009a) are: relevance (how relevant is this for me?), implications (how does this event influence my goals and/or well-being?), coping potential (how well I can cope with it?), and significance (what is this event's significance for me?). These criteria are thought to be processed at different mental levels such as sensory-motor, schematic and conceptual.

The appraisal models are often criticized for being overly 'cognitivistic', and that they cannot seem to account for a rapid onset of emotional reactions or bodily influences (like reflexes causing affective changes). The critics are mainly against the premise that the cognition (appraisals) always comes before and that it causes both the bodily reactions and the emotional experience (e.g. Zajonc, 1984; Damasio, 1999). It has also been argued that the appraisal dimensions alone cannot account for the emotional experience; and that it is not clear that these dimensions

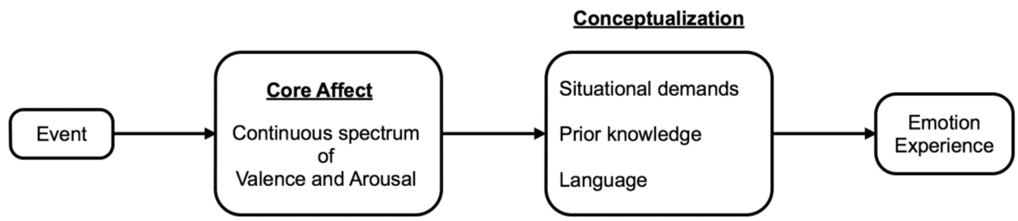

Figure 2.3 The figure depicts a schematic view of the Conceptual Act Theory (Barrett, 2006a; in press). The core affect is the individual's ongoing neurophysiological state, and changes in the core affect induced by an event can be categorized by the conceptual knowledge that involves embodied knowledge on emotion categories and is supported by language. The emotion experience is formed as a result of this conceptualization process that categorizes the momentary core affect tailored by the conceptual knowledge, the cultural influences and the situational demands.

can represent the most significant aspects of the emotional experience in a non-Western context (Barrett, Mesquita, Ochsner & Gross, 2007b). Finally, the exact set of appraisal dimensions change and gets updated to keep a coherent model. Criticizing this fact Russell (2009, p.1271) wrote: "*Rather than listing those cognitive processes involved in emotion, we might ask which sensory-perceptual-cognitive process is not involved. It might be a shorter list.*"

2.1.3 Psychological Construction

The psychological construction approach to emotion generally refers to a hypothesis that emotions are mental events that are constructed out of more basic psychological processes that are not specific to emotion (Barrett, 2013; Gendron & Barrett, 2009). The basic psychological ingredients constructing emotions differ to some extent across models. Some of them are sensory stimulation, executive functions (e.g. attention), prior knowledge, memories and semantic knowledge.

A recent, highly influential psychological construction model of emotion is suggested by Barrett and her colleagues (Barrett, 2006; 2009; Barrett et al., 2007b; Barrett, Wilson-Mendenhall, & Barsalou, in press). Their Conceptual Act Theory (CAT; Figure 2.3) is built upon the concept of the core affect (Russell, 2003; 2009). The core affect is defined as an organism's ongoing neurophysiological state that represents its relation to changing environmental and mental events. It is a kind of 'neurophysiological barometer' that represents an organism's relation to the environment, which can be categorized during an emotional experience.

The core affect, which is described in detail in the next section, is often experienced as a feeling of pleasure (or displeasure) with some level of arousal. It is a continuous assessment of one's state; and both the external and the internal events can cause changes in it. The ability of a particular event to cause a change in the core affect is called the affective quality of that event. According to Russell (2003), intense changes in the core affect can fill the consciousness i.e. the individual becomes aware of its core affect. At this point the current core affect can be attributed to an object in order to link it to its cause. The cause can be obvious (e.g. encountering a bear), or not (e.g. a subtle change in the music), and mistakes can be made (misattribution).

According to CAT, changes in the core affect can be categorized by the conceptual knowledge, sometimes referred to as conceptualization. The conceptual knowledge is thought to involve embodied knowledge on emotion categories (that can be acquired in childhood, i.e. prior experiences) and is supported by language (Barrett, 2006; Lindquist, 2013; Gendron, Lindquist, Barsalou, & Barrett, 2012). Conceptualization is the process of making meaning out of the sensation from inside and outside the body using this knowledge. Therefore, CAT suggests that en event (e.g. encountering a bear) causes a change in the core affect (e.g. elevated heart rate, feelings of displeasure with a high level of arousal) and the categorization of the core affect leads to the discrete emotion categories (e.g. fear). In CAT, discrete emotions are far from being natural kinds; instead they are formed by the conceptual knowledge and tailored by cultural influences and situational contexts. Barrett (2006) makes the analogy between seeing colors and experiencing emotion; that is, the sensation of a continuous entity (core affect or light spectrum) is categorized using the conceptual knowledge to form the discrete categories (emotion categories such as anger and happiness; or colors such as red or orange).

The purpose of this section was to illustrate the variety of approaches in explaining the concept of emotion in psychology. There are other theories that may not totally fit in any one of the main approaches discussed above. Such theories may have their focus on the specific aspects of emotion deemed most significant, such as motivation (e.g. Lang & Bradley, 2010; LeDoux, 2012). For example, Lang and Bradley (2010) suggested that the experienced emotions serve an adaptive function by providing cues for allocation of attention and mental resources. Emotions facilitate sensory processing and attention, and mobilize the organism if necessary. LeDoux (2012) focuses his investigation on the survival circuit concept in understanding how individuals survive and thrive by responding to challenges and opportunities. These ideas are further discussed in Chapter 4.

2.2 Core Affect

The first psychological constructionist approaches were introduced by Wilhem Wundt and William James (Gendron & Barrett, 2009). James (1884; 1890/1950) focused on the bodily changes (i.e. somatic, visceral, and motor information from the body) that follow directly the perception as the building block of the affective phenomena. Wundt (1897/1998), on the other hand, focused on the mental part of the affective phenomena. He suggested that affect is one of the fundamental ingredients of the human mind and that one's affective state at any given time has three qualities: pleasure-displeasure (hedonic valence), excitation-quiescence (arousal), and strain-relaxation (intensity). Hence, these properties can be used to explain one's affective state. Wundt's approach is generally cited as the "dimensional approach" in emotion psychology.

The concept of the core affect that builds on a dimensional approach is defined as a state of pleasure or displeasure with some degree of arousal (Russell, 2003; 2009; Barrett, 2006a; Barrett & Bliss-Moreau, 2009; Lindquist; 2013). Valence, together with arousal, forms a unified state; and it is called 'core' because one cannot feel pleasantness (or unpleasantness) completely isolated from arousal. However, it is possible to focus on either property at any given time. The core affect, which is a continuous state, represents feelings from the body (i.e. somatovisceral, kinesthetic, and neurochemical influences) integrated with the incoming sensory information. It influences emotional and motivational (e.g. to approach or avoid people, events or places) state of the individual. The core affect (i.e. valence and arousal) underlies all the discrete emotion categories and experiences, as suggested by a number of recent psychological constructionist theories (Russell, 2009; Barrett, in press; Lindquist, 2013). Further, for comparison of qualitatively different experiences, the core affect can provide a common ground (Cabanac, 2002).

The neural basis of the core affect has also been studied; and a distributed network (or a neural reference space) for realizing the core affect has been suggested. This reference space includes the amygdala, the anterior insula, the ventral striatum, parts of the anterior cingulate cortex, and the visceromotor and sensory integration networks in the orbitofrontal cortex (for detailed accounts, see; Barrett & Bliss-Moreau, 2009; Lindquist et al., 2012; Barrett et al., 2007b).

I have already stated that according to the dimensional approach of core affect a person's affective state at any given moment can be described by valence and arousal. This is equivalent to representing one point in a two dimensional space (Russell, 1980; 2003). The horizontal dimension in Figure 2.4 represents the hedonic valence ranging from unpleasant states on one end to pleasant states on the other. The vertical dimension represents the level of arousal ranges from low activity levels (e.g. sleepiness) to high activity (e.g. being awake). Thus, the two bipolar dimensions of valence and arousal form the 'affect circumplex' (Russell, 1980). The scientific evidence suggests that valence and arousal are the most replicable aspects of the affective responding, such as judgments of facial behaviors, subjective ratings of emotional episodes, and judgments of emotion-related words (for a review, see; Barrett & Bliss-Moreau, 2009). Further, it seems like humans can easily distinguish pleasant and unpleasant affective states. Many, but not all, can tell if they are in an affective state of high or low arousal (Barrett, 2006a; 2006b). Hence, the affect circumplex with these dimensions are used widely as a descriptive tool (e.g. Bradley & Lang, 2000; Mauss & Robinson, 2009).

In the research presented here, I also employed the affect circumplex in emotion measurement. At the subjective level, emotional reactions of human participants to auditory stimuli were measured using bipolar scales of valence and arousal. Using this method, one can measure

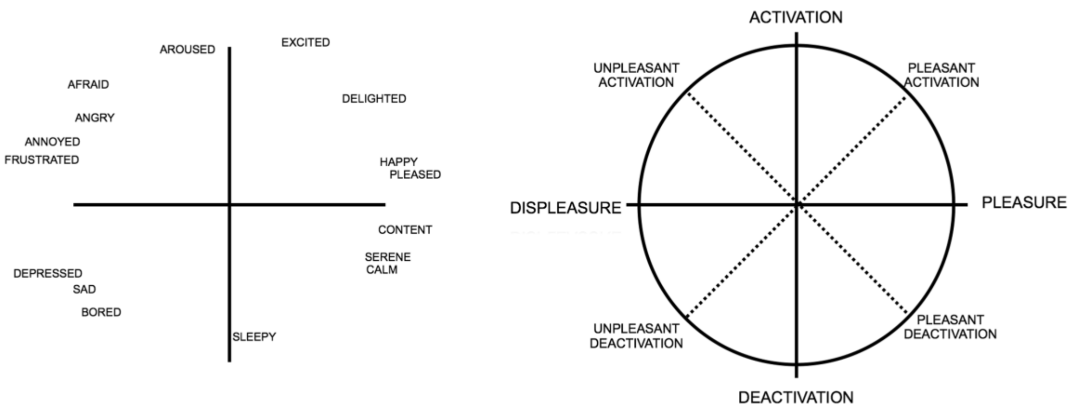

Figure 2.4 **(A)** The plot shows a multidimensional space generated from the dissimilarity ratings of emotion words (adapted from Russell, 1980). The emotion words formed a circular arrangement in a two-dimensional space. **(B)** The 'affect circumplex' is formed by orthogonal valence and arousal dimensions (adapted from Russell, 2003).

the affective quality (i.e. the ability to cause change in core affect) of auditory stimuli.

2.3 Auditory-Induced Emotions

In our daily life, auditory perception is ever present. We are usually subject to continuous stream of auditory stimulation from our surroundings. Sounds provide information about events that are close and distant as well as occurring outside one's visual field. They are also very well-suited to carry biologically significant emotional information, such as conspecific vocalizations (Armony & LeDoux, 2010). Further, it has been shown that sounds evoke emotions in its listener (e.g. Asutay et al., 2012; Bergman, 2013; Bradley & Lang, 2000; Tajadura-Jiménez, Väljamäe, Asutay, & Västfjäll, 2010a; Tajadura-Jiménez, Larsson, Väljamäe, Västfjäll, & Kleiner, 2010b).

Auditory-induced emotions were investigated thoroughly by Tajadura-Jiménez (Tajadura-Jiménez 2008; Tajadura-Jiménez & Västfjäll, 2008). In her work, she suggested four determinants of auditory-induced emotions: (1) physical, (2) psychological, (3) spatial, and (4) crossmodal. The physical determinants are related to the physical form of auditory stimuli, such as loudness, pitch, duration, onset transients, etc. Effects of the physical features of sounds on emotional reactions are best studied using tone and noise complexes as in basic psychoacoustic research (Fastl & Zwicker, 2007). For instance, it has been suggested that the perceived loudness and sharpness of a sound without meaning is related to the valence and the arousal dimensions of the core affect, respectively (Västfjäll, 2012). Hence, the basic acoustic features are capable of altering one's core affect.

The psychological determinants are related to the identification of the sound source; that is, specific meaning and interpretation of the sound for the listener. To study the psychological determinants of auditory-induced emotions, an ecological approach to sound perception and psychoacoustics is employed (Neuhoff, 2004). Usually, natural sounds are used to assess the emotional reactions to sounds. Such a study was conducted by Bradley and Lang (2000), where they used visual scales and psychophysiological methods to assess participants' emotional reactions to sixty different naturally occurring sounds. This study led to the creation of the International Affective Digitized Sounds (IADS; Bradley & Lang, 2007) database. In order to investigate the affective quality of the meaning associated with the ecological sounds, the author and colleagues (2012) used the IADS sounds. In our study (Asutay et al., 2012), a Fourier-time-transform algorithm was used to reduce the identifiability of the sound source without altering the spectral and the temporal variation in the sound. The results indicated that auditory-induced emotions to ecological stimuli were dominated by the meaning attributed to the sound by the listener.

The spatial information provided by acoustic stimuli also has an affective quality. Sounds can be very close to our body; they can move in space and provide cues about the acoustic space that we occupy. For instance, previous research found biases in behavior and cortical activity in favor of approaching compared to receding sounds (e.g. Hsee, Tu, Lu & Ruan, 2014; Maier & Ghazanfar, 2007; Seifritz et al., 2002). It has also been shown that the approaching sounds were more negative and arousing compared to the receding sounds (Tajadura-Jiménez et al., 2010a). The affective quality of auditory spatial information has also been studied for mediated environments, like virtual reality: emotion and feeling-of-presence were closely linked and they both increase with improved spatial sound resolution (Västfjäll, 2003). Further, the effects of distance, location and room size on auditory-induced emotion has been studied (Tajadura-Jiménez et al., 2010b). Finally, the crossmodal determinants refer to the influence of information from other modalities on auditory-induced emotion. In particular, this occurs when emotionally significant information from one modality influences another, which combines the multisensory integration research with emotion psychology (for a review, see Tajadura-Jiménez, 2008).

3. Auditory Perception & Attention

The auditory perception is a fundamental part of our interactions with and experience of our surroundings. We receive a continuous stream of auditory information about the external environment, as we cannot disrupt that stream in an analogous way to closing our eyes. Due to this fact, some have hypothesized that the auditory system is evolved as an alarm system that scans our surroundings, detects the significant events and objects in it, and signals for an attention shift to the prioritized targets (Juslin & Västfjäll, 2008). The auditory perception that includes both listening (active, attentive) and hearing (passive, pre-attentive) contains detection, analysis and comprehension of sounds. In this chapter, a discussion of the basic properties of auditory perception and attention is presented. First, the fundamentals of the auditory system physiology are explained, and the basic perceptual properties of auditory stimuli are discussed. Then, sound localization in humans and the processing of auditory spatial information are explained. Finally, I discuss the concept and functioning of the auditory attention.

3.1 The Auditory System

The auditory system transforms acoustical and mechanical signals into neural signals that results in the perceptual character of sounds (for detailed accounts on the auditory system, see Fuchs, 2010; Moore, 2012; Rees & Palmer, 2010). The auditory system can be considered starting at the ear, which is specialized in sensing the local pressure fluctuations in the air. The external part of the ear called pinna collects and focuses the sound energy. The sound waves travel through the ear canal and set the ear drum in motion. The three bones in the middle ear amplify and transmit the oscillations from the ear drum to the inner ear. The mechanical oscillations travel through the fluid in the cochlear canals and set the basilar membrane in motion. The hair cells (receptor cells) generate action potentials due to basilar membrane movement. In this manner acoustical and mechanical signals are converted into neural signals.

The auditory nerve carries the information generated by the cells on the basilar membrane to the cochlear nucleus where the first stage of auditory processing takes place. From there the information is projected to several other targets: the superior olivary complex (the first place the information from the two ears interact), nucleus of the lateral leminiscus (processing of the temporal aspects of the auditory stimuli which is important for sound localization), and the inferior colliculus (a major integrative center where auditory information interacts with the motor system to initiate auditory-guided behavior). The information processed in these brainstem and midbrain stations is sent to the medial geniculate nucleus in the thalamus, which serves as a relay station that takes signals from the periphery and passes the information to the primary auditory cortex (A1). A1 is located at the superior part of the temporal lobe. The adjoining areas are referred to as secondary auditory cortex (A2) or auditory belt areas, where higher-order auditory processing takes place (Woods et al., 2009). Further, the belt areas in auditory cortex show greater attentional modulation than auditory core areas (A1) do, while the core areas have higher sensitivity to stimulus features compared to the belt areas (Woods et al., 2010). It seems that the neurons in the entire auditory pathway have frequency tuning, i.e. they have preferred frequency regions that they respond to. Further, in most auditory areas there is an orderly correspondence between the specific frequency tuning of the neurons and their locations, which is referred to as tonotopic organization.

3.2 Sound Perception

Similar to other sensory modalities, in the auditory modality the perception of sound is characterized by a number of subjective characteristics. The main perceptual characters of auditory stimuli are: loudness, pitch and timbre (Fastl & Zwicker, 2007). Loudness is one of the most important low-level auditory features, and is the perceptual equivalent

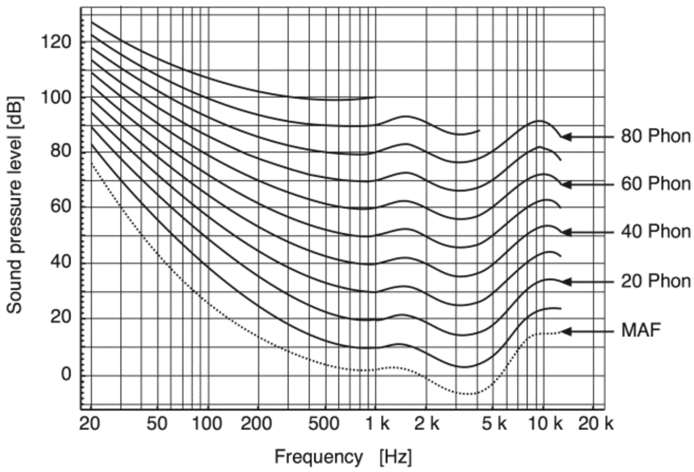

Figure 3.1 Individual curves show the sound pressure level (SPL) of a test tone to be heard as equally loud at different frequencies (i.e. equal loudness contours; [from ISO 226:2003]). As can be seen loudness depends on both SPL and frequency (MAF – Minimum audible sound field).

of sound intensity, which is measured as the sound pressure level (SPL; expressed in decibel (dB) units). However, loudness level only roughly correlates to sound intensity. The human hearing has an approximate range from 20 to 20000 Hz. However, the sensitivity of the auditory system is not constant over this range. The human hearing system is most sensitive around mid-frequency ranges (roughly from 100 to 5000 Hz), where the speech signals have the most energy. Hence, the perceived loudness of a signal is a function of sound intensity and frequency (Figure 3.1). It has been suggested that sound intensity and loudness is best represented by the basilar membrane velocity and the auditory nerve discharge rates (Young, 2010).

Pitch is another main subjective quality of auditory stimuli that is related to the spectrum and the frequency content of the sound. Similar to loudness, experience of pitch is only roughly correlated to the physical dimension of frequency. Pitch perception arises due to tonality, harmonicity and periodicity of the acoustic signal. Hence, both spectral and temporal aspects of auditory stimuli contribute to pitch perception. For instance, Figure 3.2 shows three different sounds that have the same pitch. As stated earlier, the neurons in almost the entire auditory pathway have frequency tuning. Therefore, pitch processing occurs in both cortical and subcortical structures (for a detailed account, see Wang & Bendor, 2010).

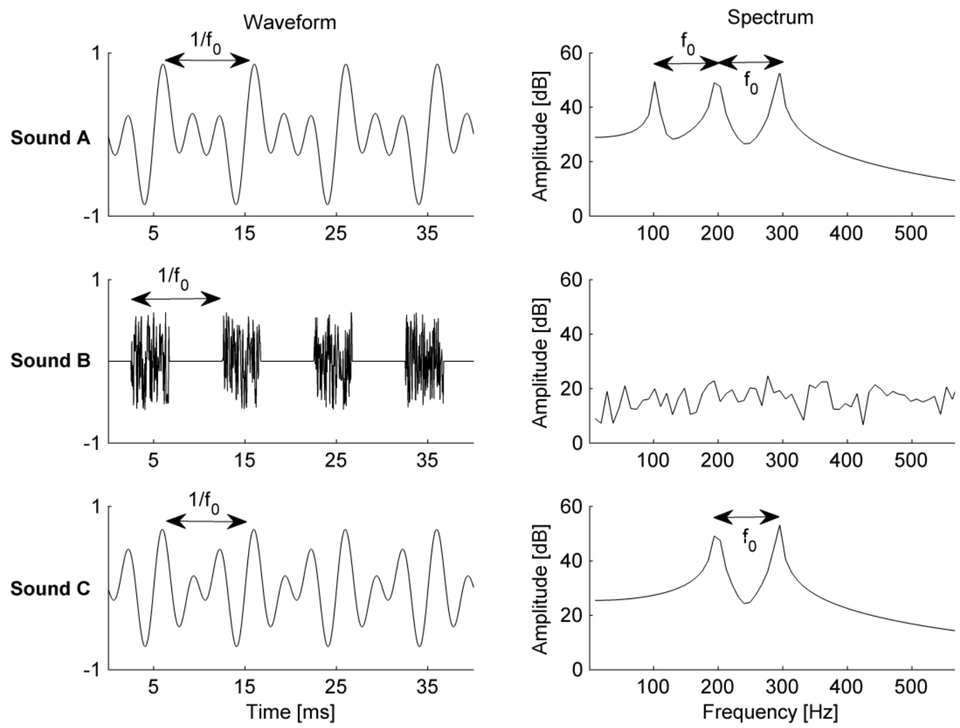

Figure 3.2 The figure illustrates three different sounds that have the same pitch (f_0=100Hz). Sound A is a harmonically organized signal with a fundamental frequency at 100 Hz including 2 overtones (200 and 300 Hz) at different intensities. Even when one removes the fundamental (resulting signal in Sound C) the pitch perception would not be affected. Sound B contains repetitive noise bursts. Even though it does not have a tonal or harmonic character Sound B would have the same pitch as the others (figure adapted from Wang & Bendor, 2010).

Two acoustic signals can have exactly the same loudness and pitch, yet they could sound entirely different. Consider the same song played by a clarinet and a trumpet. Even if they play exactly the same timing pattern with the same physical intensity, the sound from the two instruments can easily be differentiated by the listeners. Timbre is the perceptual quality of a sound that allows for the differentiation of the two instruments. Timbre is a multidimensional feature and it arises from various aspects of the sound stimuli; e.g., onset and offset transients, the relative strength of the harmonics of a tone, etc.

Even though we perceive loudness, pitch and timbre, what is heard in actuality in an everyday setting has the form of objects and events (Gaver, 1993a; Gaver, 1993b; Neuhoff, 2004). The auditory system has the ability to decompose the complex auditory input into separate perceptual streams by the help of a variety of acoustic dimensions and Gestalt principles (Bregman, 1999). Hence, what we hear is not a collection of timbres with various pitch and loudness levels, but instead it is simultaneous auditory information streams or auditory objects. The concept of auditory streaming is explained in a more detailed manner in Section 3.4 along with the concept of auditory attention.

3.3 Sound Localization

Localizing sound sources is a challenging task for the auditory system. In contrast to the visual system, where the retina forms a topographic map maintained through the sensory processing, the auditory system seems to lack a topographic representation of space (Gazzaniga, Ivry & Mangun, 2009; Purves et al., 2013). Spatial information has to be computed using several cues from the signals that arrive at respective ears. Behavioral and psychophysical studies indicated that intensity and arrival time differences at respective ears (i.e. interaural level difference, ILD; and interaural time difference, ITD) provide sound source localization cues. ITD is the main cue for localizing low-frequency sounds (ca. below 2 kHz). Above 2 kHz, ILD seems to be more useful for computing the perceived azimuth (Blauert, 1997). Apart from these binaural cues the auditory system also makes use of the monoaural cues to compute spatial information. These are mainly due to the shape of the outer ear that causes spectral modulation of the incoming sound depending on its direction. Even though the monoaural cues are highly frequency dependent, they can be especially useful to locate sound sources in the median plane (e.g. directly in the front or behind), where ITDs and ILDs do not occur. The frequency content and the intensity of the sound, and the region of space from where it originates determine the relative contribution of these cues for the computation of the source location (Blauert, 1997).

The exact nature of the neural processing of spatial information in the auditory system is currently debated. Nevertheless, it seems that the superior olivary complex (SOC) in the brainstem is the first region where ITDs and ILDs are processed (King & Campbell, 2005). The neurons in the medial superior olive (MSO) function as coincidence detectors creating delay lines from each ear, so that ITD-sensitive neurons can be activated (Ahveninen, Kopco & Jääskeläinen, 2014). It has been suggested that a separate pathway in the SOC involving the lateral superior olive (LSO) is responsible for representing ILD based on the firing rate (Yin & Kuwada, 2010). The outputs of these structures converge in the inferior colliculus

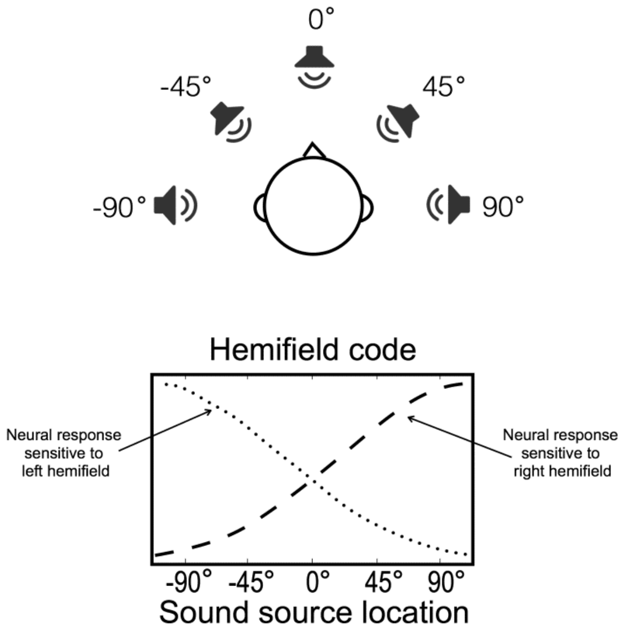

Figure 3.3 The hemifield code consists of two neural populations widely tuned to either side of the acoustic space. The azimuth angle of the sound location is represented by the joint activity by these populations. The higher localization acuity for the frontal angles is claimed to be represented by the larger changes in activity of individual neural populations (around 0^o in the plot).

(IC) in the midbrain. Additional spatial processing takes place in the IC, which could also be the first place where neural sensitivity to sound motion arises (Malmierca, 2005). Information from the IC is transmitted to the superior colliculus (SC), where an auditory space map is formed. The SC neurons also receive input from visual and somatosensory systems to construct a multisensory representation of space (Stein & Stanford, 2008). Ascending projections from the IC pass through the thalamus to the auditory cortex, whose specific contribution in auditory localization is not clear (King & Campbell, 2005).

Recent research into the spatial processing in the auditory cortex has led to a two-channel model (i.e. hemifield code), where two neuronal populations broadly tuned to the left or the right side of the auditory space (Stecker, Harrington & Middlebrooks, 2005; Salminen, Tiitinen & May, 2012; Phillips, 2008). According to the hemifield code, each of the two neuronal populations is tuned to one acoustic hemifield and their joint activity provides the azimuthal perception (Figure 3.3). Even though there is clear evidence for the existence of such a hemifield code (e.g. Stecker, Harrington & Middlebrooks, 2005), additional mechanisms are needed to explain how we can discriminate front from back, near from far and vertical directions.

3.3.1 'What' and 'where' streams

Recent studies have provided accumulating evidence for a dual pathway model in auditory processing. In particular, neuronal populations located in the anterior non-primary auditory cortex were found to be more sensitive to non-spatial acoustic qualities (e.g. pitch) in comparison with the spatial information. On the other hand, the posterior areas in non-primary auditory cortex were more responsive to spatial information than phonetic or pitch changes (Ahveninen et al., 2006; Alain, Arnott, Hevenor, Graham & Grady, 2001). These results provided evidence for the existence of an auditory processing model where auditory 'what' (identity) and 'where' (location) information are processed by ventral and dorsal pathways, respectively (Kaas & Hackett, 1999; Rauschecker & Tian, 2000). In a recent review, Alain and Arnott (2011) argued that the auditory spatial processing taking place in the dorsal pathway can have the function of orienting the visual system to a particular location of interest.

3.4 Auditory Attention

The auditory system receives complex input from the outer environment. Yet, we can rapidly and accurately detect and identify objects around us in a seemingly effortless manner. The auditory attention helps us orient towards the sounds that are significant for us. It has been suggested that the auditory system can decompose the incoming auditory input into separate streams of information based on physical and perceptual principles in a pre-attentive way (Bregman, 1999). Then, these streams that are perceived as coherent entities compete for attentional resources to dominate perception and guide behavior (see Fritz, Elhilali, David & Shamma, 2007; Shinn-Cunningham, 2008). The role of attention in stream segregation (i.e., whether one needs attention to segregate auditory streams or it occurs pre-attentively) is still under debate (Carlyon, 2004; Shamma & Miceyl, 2010).

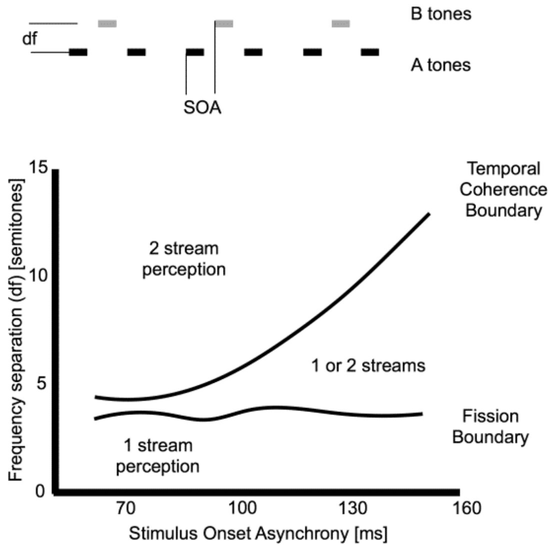

Figure 3.4 Schematic representation of auditory stream segregation of the ABA- pattern is depicted in the figure. The frequency separation (df) between A and B tones, and the stimulus onset asynchrony (SOA) influences the single or double stream perception. The plot (adapted from Van Noorden, 1975) indicates df and SOA combinations to produce 1- and 2-stream perception. In the middle region participants can have either perception depending on their intention and attention.

3.4.1 Auditory stream segregation

The most well-known demonstration of the auditory stream segregation is the presentation of two tones at different frequencies (A and B) in a pattern of repeating triplets (Figure 3.4). When the sequence is played slowly and the frequency difference between A and B (Δf) is small, then people would hear a galloping rhythm. Nevertheless, as one increases the speed and/or the frequency separation (Δf), people would start hearing two separate, concurrent sources with their own rhythm (Bregman, 1999). Perception of separate streams in a complex auditory scene depends on both the stimulus characteristics (e.g. loudness, pitch, and location) and the listener's intentions (e.g. attentional and motivational state). The latter part can be illustrated by the ability to focus on and to listen to one instrumental section while listening to a full orchestra. Alternatively, one can attend to the music as a whole, but never both. Ample research has investigated the mechanisms of auditory stream formation. Frequency, location, phase, and temporal envelope differences between successive sounds can facilitate the stream segregation (for a review, see; Moore &

Gockel, 2012). Further, it was shown that stream segregation can be influenced by the perceptual context (e.g. stimulus history) as well (Snyder, Carter, Lee, Hannon & Alain, 2008). The studies investigating the neural mechanisms in stream formation provided evidence that both periphery and auditory cortex plays a role in stream segregation (for detailed accounts, see; Micheyl et al., 2007; Snyder & Alain, 2007).

3.4.2 Attentional modulation of auditory processing

The sensory processing is influenced by both exogenous (stimulus-driven) and endogenous (voluntary) attention. Recent neuroscientific evidence indicated that the attentional modulation of auditory cortex facilitates processing of behaviorally relevant sounds (Petkov et al., 2004). Spatial sensitivity of the auditory cortex is enhanced by engaging both auditory (Lee & Middlebrooks, 2011) and visual tasks (Salminen, Aho, Sams, 2013). Further, the auditory cortex shows both attention-driven (Ahveninen et al., 2011) and learning induced neural plasticity (i.e. changes in the neural responding due to changes in stimulus statistics, behavior, environment, motivation, etc.; Ohl & Scheich, 2005); and acquires specific memory traces (Weinberger, 2004) to adapt to the ever-changing nature of the auditory scene (Dahmen, Keating, Nodal, Schulz & King, 2010; Nelken, 2004). Apart from the cortex, the auditory brainstem responses also seem to be modulated by the selective attention (Lehmann & Schönweisner, 2014) and the working memory load (Sörqvist, Stenfelt & Rönnberg, 2012). Descending projections from the auditory cortex to the inferior colliculus (IC) has been shown to be essential for learning induced plasticity (Bajo, Nodal, Moore & King, 2010). Taken together, these results suggest that the auditory processing is dynamic and constantly optimized to adapt to the changing environments and to process biologically and behaviorally significant stimuli.

3.5 Auditory Network Architecture

The empirical evidence reviewed above (and more, see; Weinberger, 2010) pointing to the adaptive capacity of the auditory system leads to the idea that the auditory cortex is not a mere acoustic analysis station. Weinberger (2010) argues that the auditory cortex deals with higher-order auditory challenges by integrating non-auditory information (e.g. motivation, attention, motor function, etc.) to its analysis. Further, the connectional analyses show that corticocortical, thalamocortical, and corticocollicular connections in the auditory system provide a unique architecture (Read, Winer & Schreiner, 2002; Winer & Lee, 2007). Particularly the work on the midbrain structure IC indicates that it acts as a hub in the auditory network for the construction of a higher-order auditory percept. Neural activity in the IC is sensitive to non-auditory input, such as eye movements, vision, motivation, emotion, learning-induced plasticity, and task engagement (Bajo et al., 2010; Gruters & Groh, 2012; Malmierca, 2005; Marsh, Fuzessery, Grose, Wenstrup, 2002). In short the auditory system is a network that processes the acoustic stimulus features and integrates the behavioral state (attentional, motivational, and emotional) of the organism to its analyses. The following chapter will focuses on the impact of emotional processing on perception and attention drawing mostly from the evidence in the visual modality.

4. Emotional Impact on Sensory Processing & Attention

The human brain is equipped with various mechanisms to deal with the vast amount of information flow we receive from the external world in a seemingly effective and effortless way. Those mechanisms are generally termed executive functions and selective attention (Driver, 2001), whose influence is partly discussed on the auditory processing in the previous chapter. Selective attention gives the brain the opportunity to prioritize a certain part of the total information flow from the environment depending on its momentary significance and relevance, and the motivational state of the organism (Driver, 2001; Petersen & Posner, 2012). A growing body of empirical evidence suggests that the affective significance of objects and events provide cues for attention allocation and enhance sensory processing via fast neural routes to sensory cortices (see; Chapter 4.1). As one can agree, if the emotional salience and the affective quality of objects around us modulates the way we perceive them, then these influences would be carried to higher-order cognitive functions such as memory and decision-making. The current chapter provides a review on how and why emotions can influence attention and perception, building mostly on studies in the visual domain; and it ends with discussing the functional and adaptive role of emotions for humans.

Many behavioral studies in the visual modality have provided evidence that emotional information may capture attention using various paradigms such as attentional blink, visual search, and covert spatial orienting. The main premise is that people pay more attention to emotional rather than to neutral information. In other words, emotional information comprises a special case of high-salience stimuli, which are prioritized for attentional resources. As stated above, we are bombarded by various inputs (e.g. sensory, visceral, etc.) in daily life. Since, our brains' processing capacity is limited these inputs compete for attentional resources. Both bottom-up (stimulus-driven) and top-down (selective) factors can influence the allocation of attention, or 'bias' the competition (i.e. biased-competition model of attention; Desimone & Duncan, 1995; Duncan, 2006). Emotional stimuli with their perceptual properties and biological significance can lead to attentional prioritization. On the other hand, learned emotional meaning of events and prior experiences can also bias the attentional competition. Below, I provide a review of behavioral and brain-imaging studies investigating the interplay between emotion, attention and perception in both visual and auditory modalities.

4.1 Emotions Influence Vision

Visual search tasks, where a target must be found among distractors, provide evidence that emotional stimuli may draw the attention faster compared to neutral stimuli (e.g. Öhman, Flykt, & Estevez, 2001). Also, it was reported that increased negative emotion may lead to more efficient visual information search (Becker, 2009). Further behavioral evidence that emotional stimuli more easily attract attention comes from the attentional-blink studies. In the attentional-blink task, participants are presented a rapid succession of visual stimuli, where they are expected to detect visual target stimuli. Participants often miss a second visual target (T2) when it is presented shortly after a first target (T1). However, the failure to detect T2 is lower when it is emotionally arousing (Anderson, 2005). Moreover, detection accuracy of T2 becomes worse when it was presented after an emotionally arousing T1 compared to a neutral T1 (Most, Chun, Widders, & Zald, 2005; Most, Smith, Cooter, Levy, & Zald, 2007). Importantly, these effects are not dependent on the familiarity or the physical properties of the stimuli. Similar results were found in exogenous cueing paradigms (e.g. dot-probe task), where task-irrelevant emotional stimuli orient attention to a particular region of space that facilitates the detection of a visual target presented in the same region (Posner, 1980). In the dot-probe task (for a typical trial; see Figure 4.1) participants must detect, as accurately and quickly as possible, a visual target (e.g. a dot) that is presented at the same location as one of two simultaneously presented

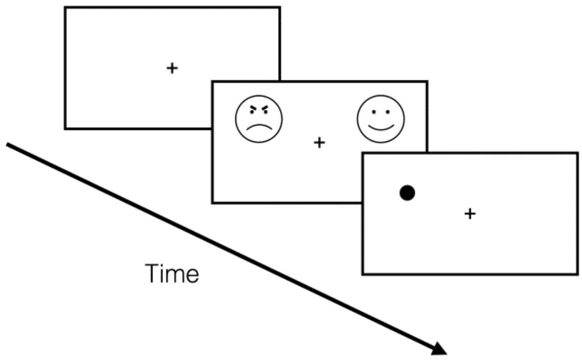

Figure 4.1 The figure depicts a typical trial of a dot-probe task. Two pictures (one negative and one neutral) are briefly presented at either side of a fixation point (<500ms). Immediately after the visual cues, a target (black dot) is presented at the previous location of one of the cues. Participant's task is to locate the target as quickly and accurately as possible. Generally the target is located faster when it replaces the emotionally negative stimulus.

prior cues, one of which is emotional (e.g. a fearful face) and the other one is neutral (e.g. a neutral face). Results typically show faster responses to targets replacing emotional rather than neutral cues (Armony & Dolan, 2002; Lipp & Derakshan, 2005; Pourtois, Grandjean, Sander, & Vuilleumier, 2004). These findings indicate that emotionally significant stimuli may attract attention more easily than neutral stimuli (Vuilleumier, 2005; Vuilleumier & Driver, 2007; Vuilleumier & Huang, 2009). In other words, the emotional significance of events and objects around us provide valuable cues for attention allocation.

Furthermore, exposure to emotionally evocative faces has been linked to differential processing of low-level spatial information (Bocanegra & Zeelenberg, 2009; Phelps, Ling, & Carrasco, 2006). In particular, the visual sensitivity and the detection threshold for the orientation of a low-spatial frequency stimulus can be improved by prior presentation of a task-irrelevant fearful face. However, the same emotional face can reduce the visual sensitivity for high-spatial frequency stimuli. Thus, it seems that negative emotion has selective influence on low-level and early aspects of visual perception (Bocanegra & Zeelenberg, 2009). Also, it has been found that negative emotional arousal influences immediate recall of visual targets (Sutherland & Mather, 2012), leads to a decreased field of view (Schmitz, Rose, & Anderson, 2009), and increases the perceived proximity of a threat (Cole, Balcetis, & Dunning, 2013). In binocular rivalry, where two images are presented to each eye and compete for dominance to reach awareness, emotional faces that are congruent with observers' current emotional state increase their dominance, which points towards the influence of affective state on the contents of consciousness (Anderson, Siegel, & Barrett, 2011). Taken together, these findings (i.e. the role of emotion on both low-level and conceptual visual perception) suggest that the affect guides the visual perception (Barrett & Bliss-Moreau, 2009). According to Barrett and Bar (2009), the brain's predictions made during visual perception carry emotional value as a necessary part of the visual experience (for a detailed discussion; see, Barrett & Bar, 2009).

Apart from the behavioral evidence reviewed above, brain-imaging studies also showed evidence pointing to the differential processing of emotional vs. non-emotional stimuli (for a detailed account, see Pourtois, Schettino, & Vuilleumier, 2013). For instance, enhancement of the amplitude of neural responses to emotional vs. neutral images can be observed in the early visual cortex (e.g. Padmala & Pessoa, 2008; Pourtois et al., 2004; Stolarova, Keil, & Moratti, 2006); which could point towards short-term plasticity in the visual cortex for early perception of emotional relevance (Keil, Stolarova, Moratti, & Ray, 2007). Further, learned affective salience of visual stimuli enhances activity in and increases functional connectivity across the early visual cortex (Damaraju, Huang, Barrett, & Pessoa, 2009). The modulated activity in the early visual areas by the affective salience can be interpreted as a gain control mechanism on lower-level sensory processing in order to enhance relevant aspects of the external environment (Pourtois et al., 2013). The emotional salience of stimuli leads to differential activity in higher-order processing. For instance, it was found that emotional pictures evoke a larger late event-related brain-potential (400-700 ms) over centro-parietal regions, which indicates the motivational relevance of affective stimuli (Bradley, Hamby, Löw, & Lang, 2007).

4.2 Emotions Influence Audition

Even though a series of studies in the 1970s have shown that fear conditioning modifies the representation of a conditioned sound stimulus in both the auditory midbrain and the cortex (for an overview; see, Weinberger, 2010), the role of emotion on attention and sensory processing in the auditory modality has not received the same interest as in the visual modality. Nevertheless, the scientific community has, in recent years, shown a growing interest in this rather understudied area.

Weinberger and colleagues have found that after fear conditioning frequency selectivity of the cells in the auditory system changes in a way to enhance responding to the conditioned frequency at the expense of other frequencies (Weinberger, 2010). These changes were relatively small and could persist for weeks. Other studies found increased perceptual sensitivity or acuity in the auditory domain after fear conditioning (for a detailed account; see, Armony & LeDoux, 2010). It was also shown that the auditory cortex response to a conditioned stimulus can be influenced by the visual context, which provides information of the likelihood of receiving an aversive unconditioned stimulus (Armony & Dolan, 2001). It is thought that the amygdala, which is an almond shape structure located in the temporal region of the brain adjacent to hippocampus with its more than a dozen of interconnected nuclei (Purves et al., 2013), plays a central role to produce the sensory plasticity (Phelps & LeDoux, 2005). Further, it was found that the learning-induced changes are mediated by the auditory cortex (Aizenberg & Geffen, 2013). Taken together, the results of fear conditioning studies in the auditory domain indicate that emotion causes subtle biases in the auditory responding to make the system more attentive and tuned to significant events. This interpretation is consistent with the adaptive capacity of the auditory system that is discussed in the previous chapter.

Apart from the classical fear conditioning literature, other studies also investigated the effects of emotions on auditory processing: Plichta and colleagues (2011) found that activation in the auditory cortex is enhanced in response to complex emotional auditory stimuli. Negative emotion induced by visual stimuli can affect auditory event-related-potentials (ERPs) as early as 20 ms (Wang, Nicol, Skoe, Sams, & Kraus, 2008). Learned emotional meaning influences the early auditory processing and engages auditory attention networks (Bröckelmann et al., 2011). Emotional context altered by reward (i.e. correct responses were awarded with either monetary gains or avoidance of monetary loss) influences the early auditory processing. As a result, the avoidance-of-loss motivation caused greater early ERPs generated in the auditory cortex compared to the monetary-gain motivation (Alexandrov, Klucharev, & Sams, 2007). Further, it was found that the auditory spatial attention can be influenced by the emotion processing that is evidenced by early ERPs around 100 ms (Pauli & Röder, 2008).

There is a lack of behavioral evidence on the modulation of auditory perception by emotional processing. For example, Yiend (2010) produced a thorough review of the behavioral findings on the attentional processing of emotional information, which contained just a handful of auditory domain studies (for reviews on neurophysiological evidence, see Pourtois et al., 2013; Vuilleumier, 2005). In the review, the main behavioral effect in the auditory domain was that it is harder to keep the emotional stimuli (e.g. one's own name or taboo words) outside the focus of attention (Yiend, 2010). Recently, using a dot-probe paradigm adapted to the auditory modality Bertels and colleagues (2010) found an attentional bias for negative spoken words (compared to neutral). However, they only found this bias when the negative stimuli were presented at the participants' right side, which they interpreted as a consequence of dominant left hemishpere processing of words in the brain (Bertels, Kolinsky, & Morais, 2010). Another recent study provides behavioral evidence that negative emotion can influence loudness perception (Siegel & Stefanucci, 2011). In their study a mood-induction technique, in which the participants were asked to write in detail about a frightening experience in their past, was employed to evoke negative emotions. The participants' loudness ratings in the negative emotion condition were compared with a control group, who wrote about their morning before arriving at the lab. As a result, Siegel and Stefanucci (2011) found that people in the negative emotion group perceived the auditory stimuli louder compared to the control group.

4.3 Functional and Adaptive Role of Emotions

Research investigating emotional processing emphasizes the importance of the amygdala (e.g. Armony & LeDoux, 2010; Phelps 2006). Evidence suggests that the amygdala plays a central role in emotion processing; and that it mediates the influences of emotion on perception and other cognitive functions such as attention, learning, memory, social behavior, etc. (Phelps, 2006; Phelps & LeDoux, 2005). Anatomical evidence shows that the amygdala receives input from both the thalamus and the sensory cortices; and has feedback projections to the sensory cortices and the higher-order areas (LeDoux, 1996). A direct, widespread projection from the amygdala to the inferior colliculus has also been documented (Marsh et al., 2002). Even though sometimes it is called the 'fear center' in the brain, the amygdala seems to function as an emotional novelty detector, since its cells respond to novel stimuli but quickly learn to ignore them unless they are biologically salient (Armony & LeDoux, 2010). The amygdala seems to be responsible for auditory learning-induced plasticity during fear conditioning (Phelps & LeDoux, 2005; Armony & LeDoux, 2010). Further, emotional vocalizations cause increased bilateral amygdala activation (Fecteau, Belin, Joanette, & Armony, 2007). Drawing from the evidence concerning emotional influences on sensory processing, attention, and other cognitive functions, researchers suggested that processing of emotionally significant events is enhanced via gain control mechanisms that are mediated by a large brain network centered around the amygdala that includes both cortical and subcortical structures (Lang & Bradley, 2010; LeDoux, 2012; Lindquist et al., 2013; Phelps, 2006; Pourtois et al., 2013; Vuilleumier, 2005). Nonetheless, the exact nature and the scale of networks may differ from one model to the other.

Theories focusing on the functional and adaptive role of emotion processing sometimes refer to the brain circuits that are activated by emotional events as the 'survival circuits' (e.g. Lang & Bradley, 2010; LeDoux, 2012). These circuits are evolved to ensure the survival of the organism and its progeny. Lang and Bradley (2010) focuses on the motivational function of emotion; and they claimed that the *"motivational arousal is the foundation of emotion"* (p.438). Emotions are grounded in the motivational states (e.g. approach vs. avoidance) that do not only enhance sensory processing and attention, but also initiate reflexes and mobilizes the organism for action (Lang & Bradley, 2010). LeDoux (2012) also focuses his research on the survival circuit concept to investigate how detecting and reacting to internal and external stimulation are central for an organism's survival. These survival circuits include brain networks involved in defense, thermoregulation, reproduction, fluid balance and maintenance of energy and nutrition (LeDoux, 2012). In sum, the amygdala centered brain networks can enhance the emotional stimulus processing, heighten attention and vigilance, initiate reflexes and mobilizes the organism for motor action.

The research focusing on the adaptive role of emotions investigates both negative and positive emotions. They mostly use punishment or reward to induce different affective reactions in participants. In the auditory domain, the work on music and emotion argues for the adaptive function of the musically induced positive emotions and their role in emotion regulation (Koelsch, 2014; Koelsch et al., 2013). For instance, it was found that positive affect induced by music is associated with increased activity in nucleus accumbens (Koelsch, 2014), which is a structure that is a part of the reward network and is sensitive to rewards such as food, sex, and money (Sescousse, Caldú, Segura, & Dreher, 2013).

5. Research Methodology

In the present chapter the focus is on the methodologies that were employed in the appended research articles. In Paper I, a conditioning paradigm was employed to manipulate the emotional significance of otherwise meaningless sounds, and to investigate the influences of affective learning on the perception of a basic auditory feature; i.e. loudness. I focused on the spatial auditory attention and its link to affective quality of ecological sounds in Papers II and III. In Paper II, using a dot-probe task adapted to the auditory modality, I investigated if the affective quality of sounds can be used as exogenous cues to orient the spatial attention. A speeded localization task is employed in Paper III to investigate emotional and attentional modulations depending on the location of the sound-sources relative to the observer's body. In Paper IV, using a change-deafness paradigm, I investigated the influence of emotional significance of auditory stimuli on the auditory attention while listening to a complex auditory-scene. In all research articles, self-reported emotional reactions were measured. Here, I present and discuss all these methods. First section deals with manipulating the emotional experience with the affective quality of sounds, where I also present the affective learning paradigm used in Paper I. Then, I present the emotion measures, where the focus is on self-reports of emotions. Finally, the behavioral tasks (i.e. change-detection, dot-probe, speeded localization) are described.

5.1 Manipulating Auditory-Induced Emotions

As was discussed in Chapter 2, we are subject to a constant stream of sounds. Sounds are very well-suited to carry biologically significant information about events that may occur close or distant to our bodies; inside or outside the focus of our visual attention. The way the auditory system functions is very much like an alarm system that scans our surroundings, detects salient events (or changes) and informs the organism to shift attention if necessary. As was discussed in Chapter 3, the auditory processing also informs the motor actions that may be taken. Also, it is well established that the sounds induce emotions in the listener. Based on the evidence reviewed in Chapter 2, I restate that different sounds possess different affective qualities depending on their acoustical and spatial characteristics, and their meaning.

5.1.1 Ecological sounds

In this body of work I mainly employed an ecological approach to auditory-induced emotions; that is, naturally occurring sounds were used to evoke emotional reactions in the participants (see, Bradley & Lang, 2000; 2007). Emotional reactions to ecological sounds usually depend on the meaning the listener attributes to the sounds. Sound characters like loudness and sharpness also have certain affective quality that has been studied with meaningless sounds (Väsfjäll, 2012), but in the case of the ecological stimuli their contributions are smaller relative to the meaning the sounds possess (Asutay et al., 2012). The auditory stimuli employed in the experiments consisted of recordings of everyday sounds emanating from various mechanical and electrical devices, human and animal actions, as well as vocalizations. Sounds depicting various events and scenes were also used (e.g. a car crash, ocean waves washing on the shore, wind rustling the tree leaves etc.). Musical sounds and uttered words were particularly avoided since the latter requires linguistic processing of the meaning of the stimuli and the former may be judged very differently depending on the individual’s musical preferences. Depending on the experimental paradigm the duration of the stimuli was adjusted (usually around 3 or 4 seconds). It can be claimed that these sounds are auditory analogues of the visual stimuli (pictures of facial expressions, animals, objects and events) used in affective neuroscience studies.

The main disadvantage of using ecological stimuli is that when studying emotional influences on perception and attention one will have to use both emotional and neutral sounds that are physically different from each other. Therefore, the differences in perception and attention found in the results can be due to the affective quality of the stimuli or purely due to the differences in spectral and temporal characteristics. In order to overcome this issue one can collect various acoustical descriptors (e.g. average loudness and pitch, and their variations) and use them as covariates in the analyses to see whether they have significant effects on the results (e.g. Paper IV in the current volume). Further, one can use physically varying sounds within emotional categories (e.g. negative, positive and neutral) as well. For instance, sounds of a baby screaming in fear and a dog growling would have completely different acoustical properties of pitch, frequency content, harmonic organization, temporal evolution, etc. Nevertheless, they are most likely to induce negative emotions with heightened arousal levels in people. Hence, using these different sounds for the same task and comparing them with different neutral stimuli (e.g. sound of a yawning person and a microwave oven) would provide a certain physical variance within the affective categories. An alternative way that is described in the next section would be to use meaningless sounds and manipulate their affective qualities with evaluative conditioning paradigms (e.g. De Houwer, Thomas, & Baeyens, 2001).

5.1.2 Affective learning and conditioning

Conditioning is one of the most extensively used learning paradigms. It involves the learning of the relationship between events that are initially represented differently. The paradigm, in its most basic form, involves two stimuli. The unconditioned stimulus (US; e.g. a mild electric shock) evokes a response (e.g. fear) with autonomic (e.g. elevated heart rate) and behavioral (e.g. facial or vocal expressions) components without any training. On the other hand, the conditioned stimulus (CS; e.g. a tone) initially has little to no effect on responding. The conditioning takes place after forming a consistent relationship between the two (e.g. repeated presentation of the tone prior to the shock). After the CS-US association is established, the CS starts to induce a similar response to the US (e.g. a fear response), that is the conditioned response (CR). This explanation is quite simple; however, in reality there are several parameters that influence the effectiveness of conditioning (for detailed accounts, see De Houwer et al., 2001; Delgado, Olsson, & Phelps, 2006; Domjan, 2005; Olsson & Phelps, 2004; Rescorla, 1988).

The emergence of the CR in response to the CS due to the formation of the CS-US pairing indicates learning. Hence, one can claim the success of conditioning by measuring the CR evoked by the CS. For classical aversive conditioning in humans, electrodermal activity (EDA) provides a robust measure to see whether the conditioning occurred (e.g. Olsson & Phelps, 2004). EDA refers to the changes in the skin's ability to conduct electricity (Boucsein, 1992; Critchley, 2002). The sweat regulation is under control of the autonomic nervous system (ANS). Thus, the changes in the electrical conductance of the skin are due to the autonomic innervations of the sweat glands. These changes involve both a tonic, slow-changing component (skin conductance level; SCL) and a phasic component with more rapid transients (skin conductance response; SCR). EDA is related to emotional arousal, stress, and orienting to novel stimuli; and it reflects activity within the sympathetic branch of the ANS. Briefly, ANS is responsible for auto-regulatory processes, such as blood pressure, heart rate, body temperature, etc. Depending on the behavioral and contextual demands (e.g. a need of a motor action, or increased vigilance) it modulates these functions in a dynamic manner. It has sympathetic and parasympathetic branches. The latter is dominant during resting-state, while the former is active to facilitate motor action (Andreassi, 2000). Increased sympathetic activity is associated with changes in blood pressure, heart rate and sweating to mobilize action by diverting blood from gut towards the limbs (Critchley, 2002). This diversion can be referred to as the autonomic arousal, and it is accompanied by changes in EDA.

It has been established that aversive stimuli (e.g. a sudden loud noise, a mild electric shock, or an angry face) elicit EDA activity (Boucsein, 1992). However, EDA is sensitive to other factors such as potential threat or reward, attention, cognitive work, and novelty. Hence, it seems that EDA responding is related to the personal significance and the motivational importance of a stimulus or an event. This fact makes it widely used in the aversive conditioning in particular (Bouscein, 1992; Olsson & Phelps, 2004) and the affective neuroscience in general (e.g. Damasio, 1999; Larsen, Berntson, Poehlmann, Ito, & Cacioppo, 2008; Mauss & Robinson, 2009). As described above, the conditioning takes place when the CR is elicited by the CS after the CS-US association is formed via consistent pairing. Increase in EDA induced by the CS reflects that the conditioning occurred (for the contextual effects and the neural mechanisms responsible for EDA induction by the CS, see; Boucsein, 1992; Crithcley, 2002).

Recommended EDA measurement sites are either the palms of the hands or the soles of the feet (Boucsein et al., 2012). The selection may depend on the task. As long as the participants do not need their both hands to perform an experimental task, one can measure EDA with relative ease from the participant's non-dominant hand. The trend is to attach the electrodes at the palmar portions of the index and middle fingers (for a detailed description of measurement parameters, see; Bouscein, 1992; Bouscein et al., 2012; Venebles & Christie, 1973).

For the aims of the current volume, an affective learning paradigm, where emotional significance of a sound can be altered, serves a very useful purpose. In Paper I, we employed such a paradigm where the affective quality of otherwise meaningless stimuli is manipulated. The US was a startling vibration applied via a powerful shaker to the backrest of the chair

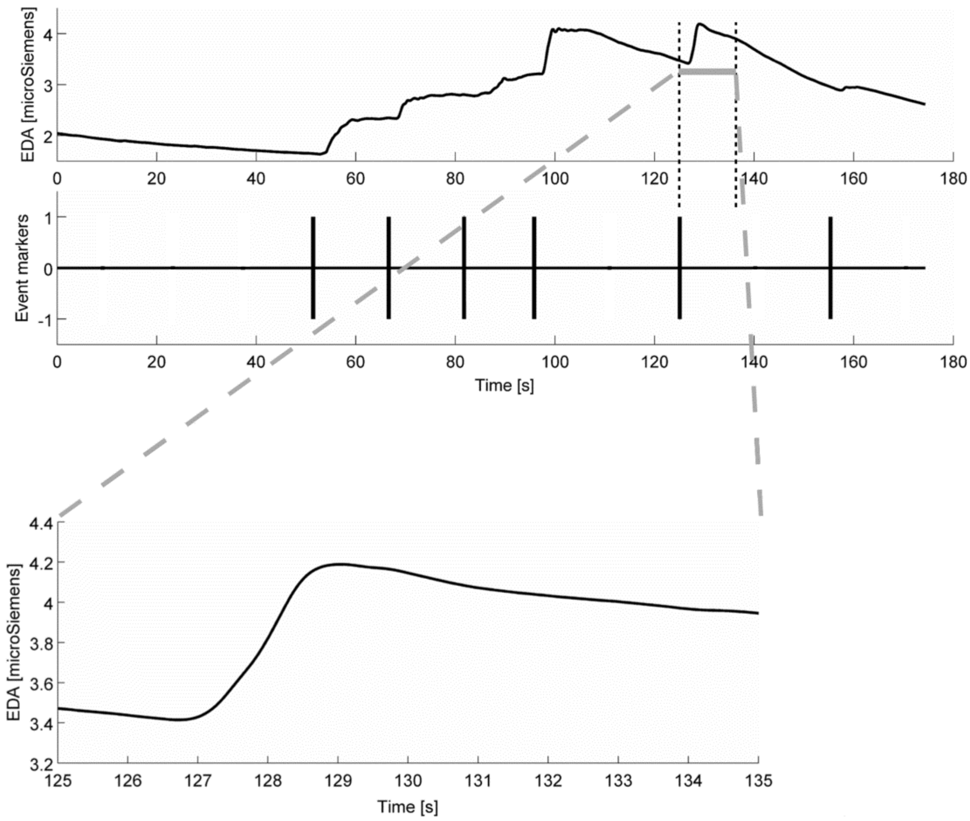

Figure 5.1 The top plot shows EDA recordings from one participant during the conditioning phase in Paper I. Event markers indicate the time when the aversive tactile stimulus is delivered. As one can observe after each delivery of the tactile stimulation participant produces a rapid increase in EDA measured as the skin conductance response (SCR).

the participants sat on (for EDA recordings from one participant during the US, see Figure 5.1). Two sound stimuli were used in the conditioning phase: band-pass filtered white noise with center frequencies of 250 Hz and 2 kHz. The participants were randomly assigned to one of the two groups: they either received 250 Hz or 2 kHz stimulus as the conditioned stimulus (CS+), and the other one served as the control stimulus (CS-). In the conditioning phase of the experiment each sound was repeated six times in random order. Each repetition of the CS+ was followed by the US, while repetitions of the CS- were not paired with the US. Measured EDA responses induced by the US, the CS+ and the CS- indicated that after successive pairing with the US, the affective quality of the sounds was modulated (Figure 5.2).

5.2 Measures of Emotion

In Chapter 2, I have suggested that emotions comprise experiential, physiological and behavioral components, almost regardless of how one approaches the subject. This implies that one can measure the emotional reactions within these three response systems (Mauss & Robinson, 2009). In short experiential measures involve self-reported (subjective) emotional

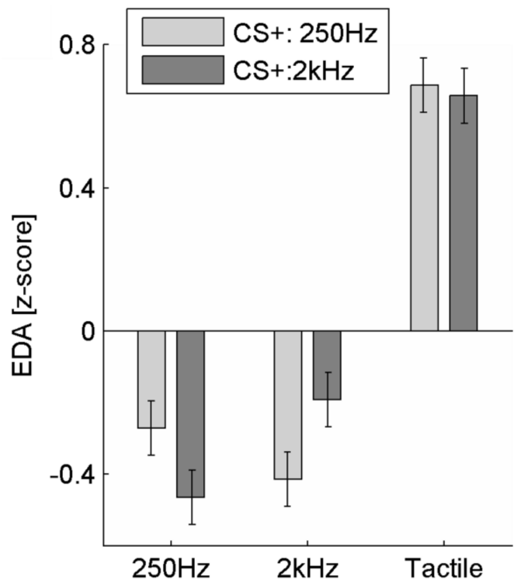

Figure 5.2 The plot shows the average EDA induced by auditory and tactile stimuli during conditioning phase in Paper I. The horizontal axis marks the stimulus, while separate bars indicate the two groups of participants depending on the stimulus they receive as CS+ (250 Hz or 2kHz; adapted from Paper I).

experiences, while behavioral measures are based on the modulation in behavioral responding (e.g. vocal or facial responding). On the other hand, physiological measures involve central (e.g. EEG), autonomic (e.g. EDA, heart rate, etc.) and/or somatic (e.g. facial-EMG) nervous system activity in response to the emotional stimuli (for a detailed account, see Larsen et al., 2008). Since measurements in these three responding systems possess their own unique sources of variance, one-to-one correlations are hard to find. At best one could find small to medium correlations in main the affective dimensions of valence and arousal or the main motivational states of approach and avoidance (Bradley & Lang, 2000; Larsen, Norris, & Cacioppo, 2003; Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005; Mauss & Robinson, 2009).

Here, the focus is on subjective (experiential) measures of emotional responding. At their very basic subjective measures of emotion assess consciously felt emotional experience. They assume the individual capacity to introspect and be able to express the experienced emotions. They can be single or multiple item measurement scales depending on the research questions and hypotheses. For instance, if one seeks to measure the capacity of a stimulus to induce a particular emotion category (e.g. fear), one could ask: *how afraid do you feel?* Recipient of this question, then, can answer it using, for example, a Likert-type scale with seven or nine points. One can also use a visual analog scale (VAS), a continuous scale, on which, the participants are required to mark a point. Apart from those, previous research also used visual scales such as Self-Assessment-Mannikin scale (SAM; Lang, 1980), Affect Grid (Russell, Weiss, & Mendelsohn, 1989) or PrEmo (Desmet, 2002). These scales using graphical representations of affective states aim to avoid misinterpretation of verbal stimuli.

As stated in Chapter 2, the affective quality of auditory stimuli has been taken as their capacity to modulate the core affect. In this perspective, auditory-induced emotions were measured using valence and arousal dimensions. Valence refers to the hedonic quality of pleasure or displeasure, whereas arousal refers to the experienced activation in response to the affective stimuli. To assess the emotional reactions to sounds the appended papers employed the SAM scales of valence and arousal (Paper I and pilot studies of Papers III and IV), and visual analog scales (Papers I – IV), see Figure 5.3. Valence and arousal dimensions are usually taken to form a two dimensional space. However, a number of studies have shown that these dimensions are not completely independent from or orthogonal to each other (e.g. Bradley & Lang, 2000; see Figure 5.4). Recently, a meta-analysis study that investigated the relationship

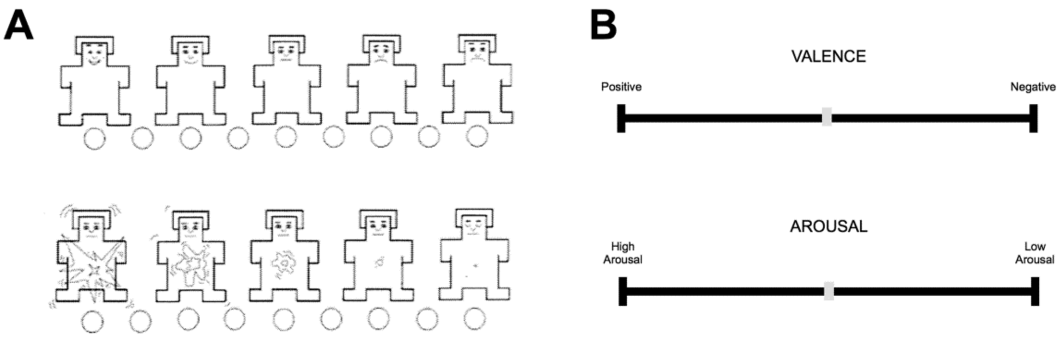

Figure 5.3 Self-reports of emotion measures employed in the appended papers. **(A)** Self Assessment Mannikin (SAM) scales of valence and arousal (Lang, 1980) are widely used in emotion research. **(B)** Visual analog scales (VASs) of valence and arousal were also used in the appended papers. The participants move the gray pointer with a mouse and mark a position in each scale to report their feelings.

between valence and arousal in self-reports concluded that there is a weak but consistent V-shaped relationship between valence and arousal, but there is a large individual variation (Kuppens, Tuerlinckx, Russell, & Barrett, 2012). Hence, the relationship between valence and arousal seems to differ depending on the individual and the context (e.g. stimulus set).

The critics of self-reports of emotion claim that the measurements reflect the way people understand and interpret the emotion language rather than the phenomenological experience of emotion. In an attempt to resolve this issue, Barrett (2004), in a study, found that the self-report measures are not purely language-based interpretations. Even though there is some evidence that linguistic interpretations cause differences in the self-report measurements, the results were still consistent with the perspective that the subjective measures of emotion largely reflect the phenomenological experience of emotion (Barrett, 2004).

5.3 Attention Tasks

In order to study the effects of emotional processing on attention, previous research employed a variety of behavioral paradigms (see Chapter 4), such as attentional blink, dot-probe, change-detection, etc (for a review, see Yiend, 2010). The current section introduces the behavioral tasks that were employed in the appended papers: change-detection (Paper IV), dot-probe (Paper II), and rapid localization (Paper III).

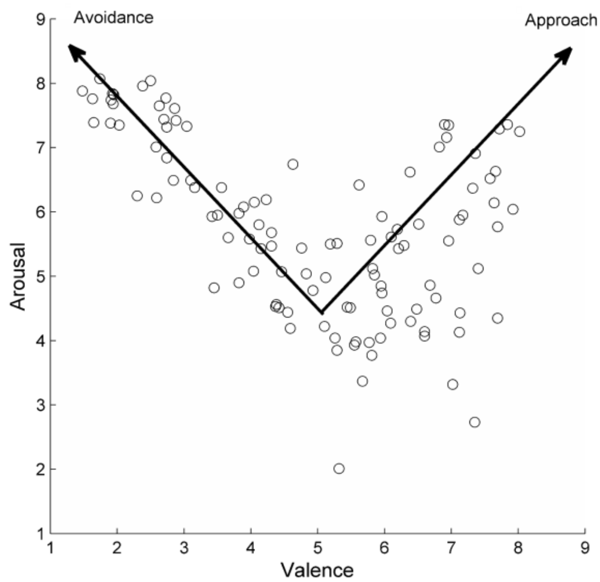

Figure 5.4 Emotional reactions to different ecological stimuli (adapted from Bradley & Lang, 2000) plotted on the two dimensional affect circumplex. Emotional reactions in the valence/arousal space spread widely on two lines, which point to a possible V-shaped relationship between valence and arousal. Bradley and Lang (2000) argued that the two arms of the V represent the motivational states. Moving from the middle (i.e. neutral) toward one end point on a line represent increasing motivation to approach or avoid.

5.3.1 Change detection

In the change detection paradigm, the participants, after listening to two auditory scenes composed of multiple sounds, simply are asked to indicate whether the two auditory scenes were identical or whether a change occurred. The paradigm is first used in the visual modality, and the failure to detect rather salient changes in a visual scene is called 'change blindness' (Rensink, 2002). When the paradigm was adapted to the auditory domain, it was also found that rather obvious changes (e.g. a talker's identity in the middle of a spoken message; Vitevitch, 2003) may be missed by the listeners; that is, 'change deafness'. As mentioned above, a typical study involves two scenes (visual or auditory) presented in sequence separated by an interval of interruption. The visual scenes can be an array of shapes or pictures, while the auditory scenes are composed of a number of co-occurring sounds. In the auditory change detection, changes take place in the forms of presentation location, sound replacement, addition or deletion. Change deafness is argued to stem from the failure to attend the changing event in the scene and/or the failure to process the sound in the short term memory (Snyder & Gregg, 2011). Previous research has shown that change deafness can be influenced by differences in physical properties of the changing sounds (Gregg & Samuel, 2008); directed attention (Eramudugolla, Irvine, McAnally, Martin, & Mattingley, 2005); semantic representations of the auditory events (Gregg & Samuel, 2009); and the capacity of the auditory short term memory (Pavani & Turatto, 2008). More recently, Backer and Alain (2012), using a change detection paradigm, found that complex auditory scenes are rapidly decomposed into object representations that are available for attentional resources, and that the top-down attention can be oriented to one of those representations which is the modulating factor in change deafness (Backer & Alain, 2012). These findings agree with the biased competition models of attention (see Chapter 4); that is, the object representations compete for attention and both top-down (selective) and bottom-up (stimulus driven) factors may bias the competition (Desimone & Duncan, 1995; Duncan, 2006; Shinn-Cunningham, 2008).

In Paper IV, the author investigated how the emotional significance of auditory stimuli can influence the attentional competition using a change-detection paradigm. The auditory scenes were composed of six co-occurring stimuli one of which was the target. In each trial, the participants listened to two auditory scenes in sequence separated by an interruption/retention period. All the five non-target stimuli in a scene were either emotionally neutral or negative; and the target was, independent of the scene valence, either neutral or negative. The changes took place in the form of replacement of one target (T1) with another (T2); and this occurred in 67 % of the trials. Hence, the factors in the experimental paradigm were scene-valence (negative or neutral), T1 valence (negative or neutral), and T2 valence (negative or neutral). For each combination, four unique auditory scenes were used (for a detailed description, see Paper IV). The task measures were hit-rate and perceptual sensitivity (d'; Macmillan & Creelman, 1991).

5.3.2 Dot-probe

The dot-probe task is a covert spatial orientation task using task-irrelevant exogenous cues (Posner, 1980; Yiend, 2010). It is typically used in the visual modality; and it involves presenting one emotional and one neutral picture simultaneously at opposite sides of a fixation point. The task is to detect, as quickly and accurately as possible, a neutral target (e.g. a dot) that follows the cue presentation. Usually the cues are task-irrelevant and non-predictive of the target location. Hence, the target appears in the previous location of either the emotional or neutral picture at equal times (Figure 4.1). The relevant measure in a dot-probe task is the reaction times to locate the target. The main hypothesis is that if emotional stimuli cause an attentional bias then the target would be detected faster when it is presented at the same spatial location of an emotional stimulus. As was discussed in Chapter 4, previous research reported that participants are faster to detect the target when it replaces the emotionally negative compared to neutral pictures (Armony & Dolan, 2002; Lipp & Derakshan 2005; Poutois et al., 2004).

In Paper II, the author adapted the dot-probe task to auditory domain, i.e. the acoustic-dot-probe task. The purpose was to study whether the emotional silence of a task-irrelevant auditory stimulus can be used as an exogenous cue to orient the spatial attention. Two ecological sounds simultaneously presented at two separate spatial locations (left vs. right; or front vs. back). The sounds were selected to form both neutral-emotional (both positive and negative) and emotional-emotional pairs. The presentation of the task-irrelevant auditory cues was followed by an acoustic target (100ms-long white noise burst), which was presented at the previous position of one of the cues. The time to detect the target and hit-rates were taken as performance measures.

5.3.3 Localization task

Finally, in Paper III a speeded localization/discrimination task was employed to investigate a possible auditory bias towards the rear perceptual field at attentional and emotional levels. In the experiment, the author first measured the participants' emotional reactions to ecological sounds using self-reports, and then employed localization task to study the differential attentional effects depending on the region of space the sound-sources were in. The sounds were presented through loudspeakers located directly in front of or behind the participants (Figure 5.5). In the localization session, participants indicated the location of each sound by pressing a button as quickly and accurately as possible. Their responses and reaction times were measured. A possible attentional bias towards a particular region of space would result in faster localization when a sound was presented at that spatial region.

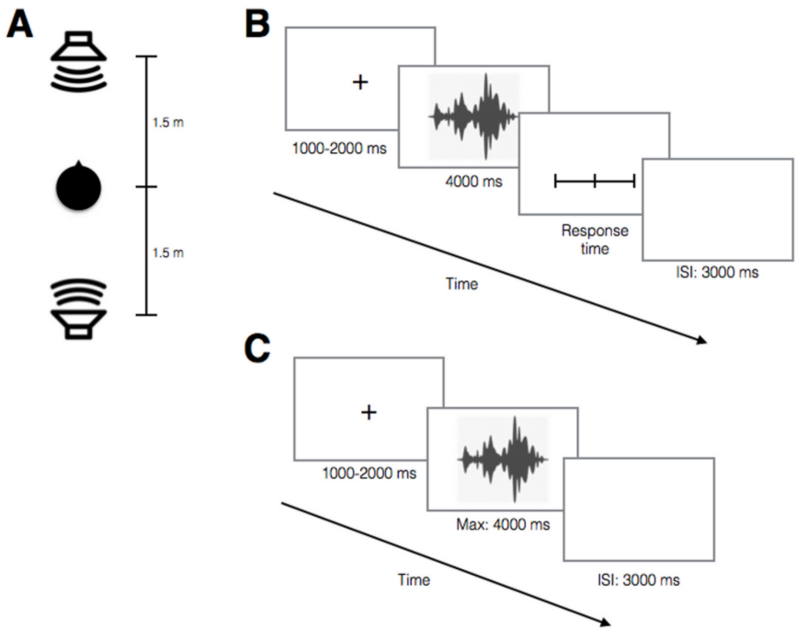

Figure 5.5 The figure depicts the experimental design of the study presented in Paper IV. **(A)** Two loudspeakers (one in the front and another at the back) were located at 1.5 m distance from the participants. **(B)** The plot shows the timeline of the first session. Duration of the fixation cross was randomly assigned, and during the response time participants reported their emotional reactions. **(C)** In the localization task, participants indicated the sound location as quickly and accurately as possible during the sound presentation (ISI: inter-stimulus-interval)

6. Aim and Overview of the Present Studies

The overarching aim of the current thesis is to contribute to the understanding of the influence the emotional processing has on attending to and perceiving auditory events and environments. The work primarily concerns the behavioral studies on the auditory features and spatial perception. With the theoretical and the methodological framework presented in the previous chapters, the current volume asks the rather broad question of:

How do the affective qualities of auditory stimuli modulate the way we attend to and perceive sounds?

More specifically, the present work focuses on a set of four fundamental research questions (RQs):

RQ1 Does the emotional learning modulate the representation of a basic low-level feature of a sound along with its emotional significance?

RQ2 Does the emotional significance of a sound influence the orientation of the auditory spatial attention?

RQ3 Can auditory spatial information possess emotional significance that in turn, causes an attentional bias?

RQ4 Does the emotional significance of a sound bias attentional competition in a complex environment?

These RQs formed a framework for the experimental designs to provide answers for the broad question above. As presented in Chapter 3, the auditory system can provide information about the identity and the location of sounds; and with the guidance of the attentional processing it can prioritize some events while pushing others in the background. Therefore, I attempted to separate these issues to some extent. RQ1 deals with the consequences of affective learning and emotional salience on the perception of a basic auditory feature, since previously, it was argued that the perception of these basic features are not affected by higher-order processing such as attention or emotion. RQ2 and RQ3 concerns the spatial aspects of auditory perception and the link between the auditory spatial attention and emotion. Finally, RQ4 has the aim to combine these issues in a complex auditory environment to study the importance of the affective quality of sounds and their spatial locations on how auditory attention and perception function (Figure 6.1).

The appended papers present the experimental protocols designed to provide answers to the RQs and the results of those experiments. In Paper I, using an aversive learning paradigm, the author investigated the influence of emotional processing on a low-level auditory feature: loudness (RQ1). The emotional significance of a sound on its ability to orient spatial attention to a particular region of space (RQ2) is studies in Paper II. For the study presented in Paper III, the focus was on the auditory spatial

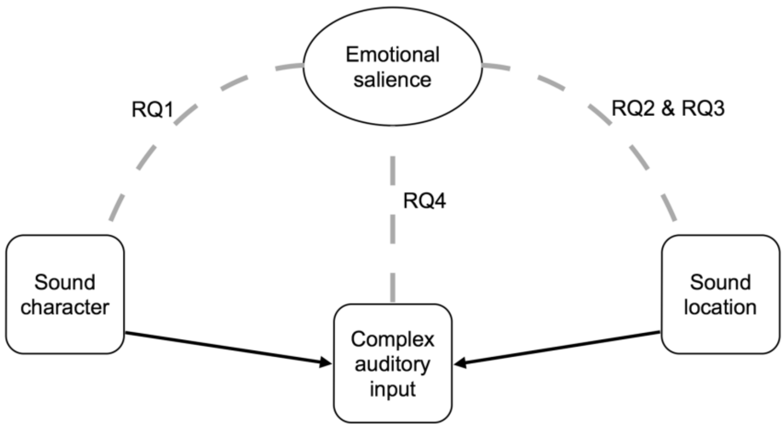

Figure 6.1 The diagram illustrates a schematic overview of the RQs and how they relate to each other.

information and its potential to possess certain affective quality, which, in turn, leads to an attentional bias (RQ4). Finally, in Paper IV, employing a change detection task, the author set out to investigate whether the emotional salience of sounds in a complex auditory environment could influence the allocation of attention to guide auditory perception.

6.1 Paper I: Perception of loudness is influenced by emotion

The aim of this study was to investigate if negative emotion can influence a basic, low-level auditory sensory dimension: loudness. Drawing form the work suggesting that the emotional salience of a stimulus (auditory or visual) alters the way it is processed and perceived (Chapter 4), and from the hypothesis that the auditory system functions as an adaptive, cognitive alarm system (Chapter 3), I claimed that the negative emotional significance would affect the loudness perception. In order to test this, an aversive conditioning paradigm was employed to induce affective learning that alters the emotional significance of otherwise meaningless auditory stimuli (see Chapter 5.1.2).

First, the participants completed a conditioning phase in which two sounds (1/3 octave band-wide white noise with center frequencies of 250 Hz and 2 kHz) were presented six times in a random order. The participants received one of the stimuli as the conditioned stimulus (CS+) while the other one was the control stimulus (CS-). Each repetition of CS+ was followed by a startling vibratory shock applied to the chair they sat on (i.e. the unconditioned stimulus; US). During the conditioning phase participants' EDA was recorded, as a valid indicator that learning occurred as a result of the consistent CS+ and US pairing. After conditioning, participants listened to and rated the loudness of four sounds (the CS+, the CS- and two other sounds with center frequencies of 500 Hz and 1 kHz) on a visual analog scale (VAS). Then, in a separate session, they rated how they felt after the presentation of each sound using 9-point SAM scales of valence and arousal (Figure 5.3). Also, in the same session the participants indicated how much fear they felt and how threatening they thought each sound was on separate VASs. The order of these two judgment sessions were balanced; that is, half the participants rated the loudness first, while the other half completed the emotion measures session first.

In our results we found that the conditioning was successful as indicated by the changes in EDA induced by the sounds. Regardless of the actual sound that were used as CS+ or CS-, EDA induced by the CS+ was higher (Figure 5.2). The subjective measures also provided evidence that CS+ gained emotional salience due to conditioning. The participants thought that the CS+ was more negative and fear-inducing than the CS-. Importantly, this effect was not due to the physical differences between sounds. Finally, we found that the aversive learning induced differences in loudness judgments as well. In sum, the results showed that the same sound was reported as more fear-inducing and negative, and perceived as louder when it was used as CS+, compared to when it was CS- (Figure 6.2).

The results shown in Paper I lend evidence that the affect is an important mechanism in auditory perception, and that it can even influence one of the most basic sensory aspects of sound: its loudness. Affective learning not only modulates the emotional significance or meaning of a sound but it also alters the low-level sensory features.

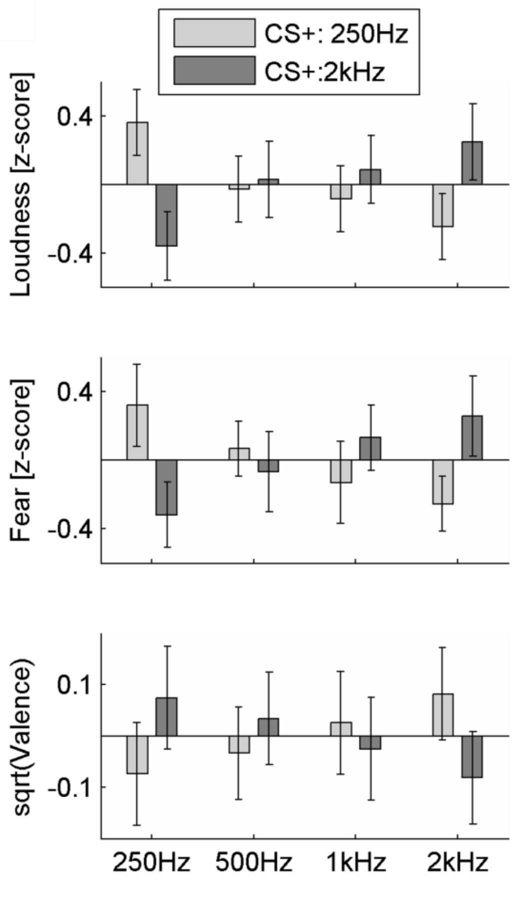

Figure 6.2 The figure shows the interaction effect of conditioning group (CS+: 250 Hz vs. CS+: 2 kHz) and sound on loudness (top), fear (middle), and valence (bottom) judgments. Main effects and grand means are removed (from Paper I).

6.2 Paper II: Negative emotion provides cues for orientation of the auditory spatial attention

The author investigated the influence of the emotional significance of a sound on the deployment of auditory spatial attention in the study presented in Paper II. In Chapter 4, I review evidence that emotion provides cues for allocation of attention and mental resources, and that people tend to pay more attention to emotional rather than neutral events. However, behavioral evidence for this effect in the auditory domain is almost non-existent.

In order to test whether the emotional salience of task-irrelevant sounds can provide exogenous cues to orient spatial attention, we used the auditory version of the dot-probe task (see Chapter 5.3.2). Six ecological sounds were selected to form three valence categories (neutral, negative and positive). Each category consisted of one human vocalization and one environmental sound. First, the participants listened to the stimuli and rated how they felt after each sound using VASs of valence and arousal. They completed one experimental block consisted of each stimulus presented at each of the four possible locations (front, back, left, and right). In the dot-probe task, two sounds were simultaneously presented at two different locations (either front vs. back, or left vs. right). The participants completed front-back (FB) and left-right (LR) parts in separate blocks. The sounds were selected to form both neutral-emotional, emotional emotional-emotional, and same-sound (same sound at both locations) pairs. The presentation of the ecological sounds was followed by the acoustic target (100ms-long white noise burst), which was presented at the previous location of one of the ecological sounds.

Reaction-time data indicated that during negative-neutral pairs, participants detected the target significantly faster when it replaced the negative stimuli compared to the neutral. The positive stimuli when paired with neutral sounds could not provide as clear an attentional bias as the negative sounds; and there were no indication of attentional bias for positive-negative pairs. Further, we found that for the same-sound pair trials in front-back task, target detection was significantly faster when it occurred behind the participants. Also, the sounds tended to induce higher arousal when they were presented behind the participants compared to in front of them.

The results of Paper II provide clear evidence that negative emotional salience provides exogenous cues to orient auditory spatial attention to a particular region of space. Also, they point towards a potential auditory bias for the rear perceptual field. Taken together, these results are consistent with the alarm function of auditory system, its function in guiding the attentional resources to a particular region of interest in space, and the ability of the emotional salience to provide cues for attention allocation.

6.3 Paper III: Attentional and emotional prioritization of the sounds occurring outside the visual field

The purpose of the research shown in Paper III was to investigate the differential attentional and emotional influences of auditory stimuli depending on the region of space they occurred around the listener. In particular, we studied if, and how, the auditory spatial information influences emotional reactions and auditory attention. The auditory system helps the organism to detect salient events around its body, and alarms for an attention shift if necessary (Juslin & Västfjäll, 2008). Further, it has a function of guiding the visual perception to a location of interest (Arnott & Alain, 2011). Thus, the ability of the auditory system to sense targets outside the visual field is critical. In this perspective, I propose that there may be an auditory bias towards the rear field at attentional and emotional levels; that is, faster detection and more intense emotions to sounds occurring behind the listener.

To test this hypothesis, the emotional reactions to ecological sounds emanating from frontal and rear perceptual fields were measured using VASs of valence and arousal. Then, a speeded localization task was employed to study the possibility for an attentional bias towards the rear perceptual field. In the first session, the participants listened to four ecological sounds presented at two different locations (front or back; see Figure 5.5); and rated their subjective emotions after each sound. In the second session, the participants indicated the location of each sound by pressing a button as quickly and accurately as possible. They completed six experimental blocks, each consisting of all stimuli presented once at each location, while their responses and reaction times (RTs) were measured.

As a result, we found that significantly stronger negative emotions were induced when sound-sources were behind the participants; and that the participants were significantly faster (lower RT) and more accurate (higher hit-rate) in detecting stimuli that were located behind them. Further, it was found that the effect of spatial information on attention is mediated by emotion as it was reflected in the negative relationship between the RTs and the emotional significance (for details, see Paper II).

The research presented in Paper III provides evidence that depending on the region of space with respect to the observer's body, auditory spatial information can be of emotional significance. In fact, crossmodal attention studies have shown that the audiotactile interactions occurring in rear-space are both qualitatively different from those in the frontal space and tend to trigger rapid defensive head and arm movements, which indicate that the frontal and the rear space representations could trigger differential sensory response properties (for reviews, see Spence, 2010; Occelli, Spence & Zampini, 2011).

6.4 Paper IV: Emotional bias in change deafness in multisource auditory environments

The aim of the study presented in Paper IV was to investigate whether the affective quality of sounds has an influence on attention in a complex auditory environment. The auditory system can decompose the complex input from the environment into separate streams, which then compete for attention to guide auditory perception (see Chapter 3). In order to investigate which auditory events receive attention and guide auditory perception, a change-detection task was employed (Chapter 5.3.1).

Using 24 environmental sounds, 96 unique auditory-scenes were formed; each consisting of six concurrent stimuli, one of which was the target sound (for details, see Paper IV). All the non-target sounds in a particular scene were either emotionally negative or neutral and the target was, independent of the others, either negative or neutral. In each trial, participants listened to two auditory-scenes separated by a brief interruption period; and their task was to indicate whether the two scenes were identical or not. Changes took place in the form of replacement of the target in the first scene (T1) with another target in the second scene (T2); and this occurred 67 % of the time (rest were catch-trials). Sounds were delivered via four loudspeakers (i.e. two in the front, two in the back; see Figure 6.3). Half the sounds in each scene were presented via the front loudspeaker pair, while the other half were presented via the rear loudspeaker pair. For the change-trials, T1 and T2 were presented at the same location; and the changes occurred in each location at equal times.

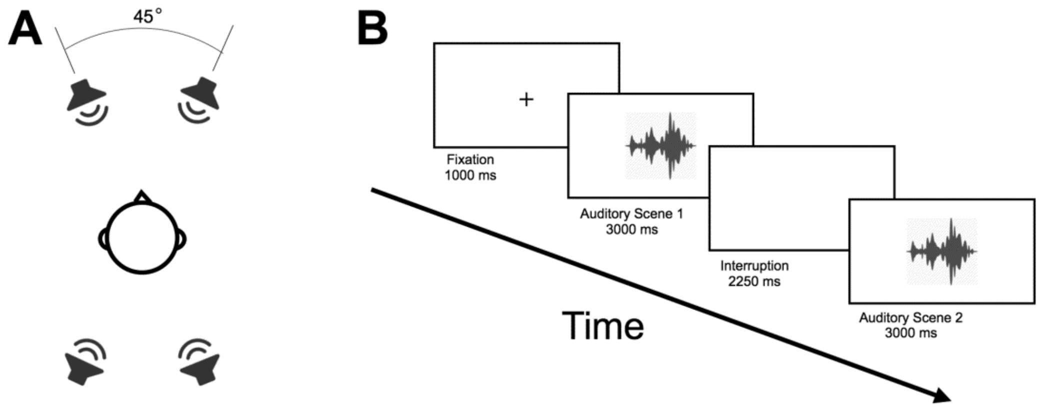

Figure 6.3 Experimental design of the study presented in Paper IV is illustrated. **(A)** Four loudspeakers (two in the front, and two at the back) were located at 1 m distance from the participants. The angle between front and rear loudspeaker pairs was 45° from the participants' point of view. **(B)** The plot shows the timeline of the change detection task. In each trial, the participants listened to two auditory scenes separated by an interruption period, which consisted of 750 ms of white noise preceded and followed by 750 ms of silence.

Thus, the experimental factors were: scene-valence (negative vs. neutral), T1-valence (negative vs. neutral), T2-valence (negative vs. neutral) and change-location (front vs. back). For each combination of the factors there were four unique trials (different target and scene combinations) in the experiment.

Both T1-valence and T2-valence had highly significant effects on hit rates, which indicated that when the changing events were emotionally negative change deafness was attenuated, compared to neutral events. Further, there was an overall increase in perceptual sensitivity (d'; Macmillan & Creelman, 1991) during the negative scenes compared to neutral scenes. We also found that the effect of T2-valence was modulated by the change-location (Figure 6.4). There was a ceiling effect for negative T2, but it was easier to detect a neutral T2 when it occurred behind the participants.

Clear behavioral results shown in Paper IV can be interpreted as the guidance of the allocation of auditory attention in a complex environment by the emotional significance of events take place within that environment. In particular, change deafness was attenuated when the changing stimuli were emotional. Also, Paper IV documented an increase in perceptual sensitivity for negative auditory-scenes. This can be interpreted as an overall decrease in auditory perceptual thresholds due to the presence of an emotionally negative and arousing environment. Previous research has argued that increased emotional arousal leads to increases in attention and vigilance (Phelps & LeDoux, 2005).

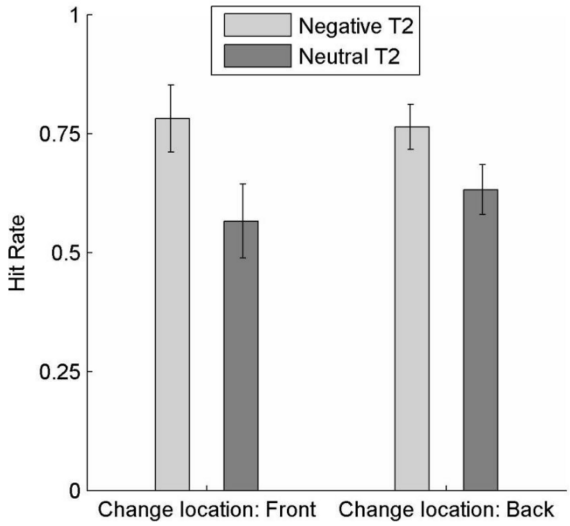

Figure 6.4 Statistically significant ($F_{1,17}$=5.33, $p<.05$, $\eta_p^2=.24$) interaction effect between change location (front vs. back) and T2-Valence (negative vs. neutral) on hit-rate (from Paper IV).

7. General Discussion & Conclusions

Perception is our everyday tool that we use to gather information from our surroundings and navigate through the environments that we occupy. Auditory information comprises a substantial portion of this information: we communicate with other people through language and prosody; hear sounds emanating from the events and the objects that occupy the space around us; receive information about the general properties of the said space (e.g. its size); listen to music and are moved by it; and so on. In fact, apart from for very special and unusual situations (e.g. being underwater, in an anechoic room, or in outer space) the amount of input we receive through our ears is overwhelming. Yet, we can effectively deal with this information thanks to the specialized mechanisms that our brains possess, such as the selective attention and other executive functions. These mechanisms grant our brains the opportunity to prioritize a subset of the total sensory input depending on its personal relevance and significance for, and the behavioral state of the individual (Driver, 2001).

Attention can influence sensory processing in both bottom-up (stimulus-driven) and top-down (selective) routes (Petersen & Posner, 2012). An obvious example for the former would be a red circle among a group of blue circles. The red circle would be noticed almost immediately due to the visual contrast it creates with the surrounding blue circles; that is, it stands out. To illustrate the top-down influence of attention, imagine you are in a crowded restaurant having an interesting conversation with your friend. Even though your mental resources and attention are directed at the conversation, you may notice if someone at another table utters your name. Hearing your name may grab your attention by disengaging you from your current activity.

The auditory attention theories suggest that the auditory system is capable of decomposing the complex input into separate streams of information with the help of spectral (pitch and harmonic relations), temporal (envelope and transients) and spatial (location and distance) properties of sounds; and these auditory streams compete for the limited attentional resources we obtain (Fritz et al., 2007; Shinn-Cunningham, 2008). Certain auditory streams due to bottom-up and top-down factors receive priority in attention (the biased-competition model of attention; Desimone & Duncan, 1995). Research in affective neuroscience suggests that the emotional significance of events and objects around us can provide cues for allocation of attention and mental resources (Dominguez-Borràs & Vuilleumier, 2013; LeDoux & Phelps, 2008; Phelps, 2006; Phelps & LeDoux, 2005; Pourtois et al., 2013; Vuilleumier, 2005; Vuilleumier & Driver, 2007) due to a possible survival related function (Lang & Bradley, 2010; LeDoux, 2012; Tooby & Cosmides, 2008). Emotional stimuli form a special case of high-salient input that may enhance sensory processing, bias attention, and influence other higher-order functions such as memory and learning. The current thesis set out to investigate how the affective dimension of auditory stimuli modulates the way we perceive and attend to the sounds occurring around us.

In this chapter, the specific contributions of the current thesis to the affective and the auditory research are discussed. First, several contributions to the emotion research are presented with the emphasis on the behavioral evidence that emotion processing influences auditory perception and on the methodological tools that can be used to study emotion in the auditory domain. Second, specific contributions to the auditory research are discussed. Then, the focus is shifted to the limitations of the current research and possible strategies to improve our scientific knowledge and understanding on the topic with further research. Finally, the chapter ends with a discussion of application possibilities for the outcomes of the present research.

7.1 Emotion Research

The current research with its focus on the emotional modulations of auditory perception has specific contributions to the affective science. First, it lends further evidence that learned emotional meaning can modulate sensory perception. In particular, the results presented in Paper I provide clear evidence that loudness perception can be influenced by negative emotion, and that this can occur through low-level affective learning. Conditioning studies in the auditory domain have shown that the consistent CS-US pairing can alter the representation of the CS via inducing plastic changes in auditory midbrain and cortex (Armony & LeDoux, 2010; Weinberger, 2010). Further, it was shown that learned emotional meaning can influence early auditory processing evidenced by magnetic event related potentials (Bröckelmann et al., 2011). However, Paper I is the first study to provide clear behavioral evidence that affective learning can influence not only the emotional significance of auditory stimuli, but also its sensory perceptual properties.

Second, the outcomes of Paper II and IV are consistent with the research on the attentional bias induced by emotional salience. It was found that the emotional significance of sounds provides exogenous cues for orienting the spatial auditory processing (see Paper II), and that the auditory attention is guided by the emotional salience of events in a complex auditory environment (see Paper IV). As stated several times in the current volume, emotions influence the attention allocation. However, most of the evidence in this area is in visual domain (e.g. Vuilleumier, 2005; Yiend, 2010). The research presented in Papers II and IV clearly demonstrates the potential of auditory-induced emotions to provide cues for attention allocation and to guide perception.

Further, the experiments presented in the appended papers provide methodological tools for studying emotions in the auditory domain. In particular, the author employed paradigms adapted from the visual domain in Papers II and IV. Even though the change-detection task has been used in auditory modality extensively (see Chapter 5.3.1), Paper IV is the first to employ the particular paradigm to investigate the modulation of auditory attention due to emotional processing. On the other hand, Paper II adapted the dot-probe task to auditory domain. To the author's knowledge there is only one other study that used an adapted version of dot-probe paradigm (Bertels et al., 2010). In their study, Bertels and colleagues used spoken words as stimuli and found an attentional bias for the negative (paired with neutral) words only when they were presented on participants' right side. Apart from the attention tasks, using an affective-learning paradigm, it was aimed to alter the emotional salience of otherwise meaningless sounds (Paper I). In order to study emotional reactions to auditory stimuli one can use ecological sounds with specific meanings, such as human and animal vocalizations. However, to study the role of emotion on auditory attention and perception one needs to use both emotional and non-emotional sounds. For naturally occurring sounds it is not an easy task to match the physical characteristics of sounds in different emotional categories. In order to overcome this issue, we decided to use a conditioning paradigm, which proved functional (see Paper I).

7.2 Auditory Perception Research

The current research also contributes to the auditory science, since it compiles a number of studies investigating the impact of emotions on auditory attention and perception. Even though the number of studies pointing to emotional biases in auditory perception and attention is growing, the evidence is still sparse compared to research in the visual modality (see Chapter 4 and its references). By showing basic and clear research results the appended papers contribute to the knowledge on the connection between emotional processing, auditory perception, and attention. Apart from this general aspect, the appended papers have specific contributions to the understanding of auditory perception and attention. Below, I present and discuss those.

The traditional view of the functional organization in the brain presents a modular architecture (e.g. Campbell, 1905; Fodor, 1983). In this architecture brain operates as a sequence of functions, each of which is performed by anatomically distinct areas. The main assumption is that the primary sensory areas are only responsible of processing the sensory input. Then, they pass the outcomes of their analysis to higher order areas that are responsible for interpreting the sensory input and planning the necessary actions. Importantly, the operation in one primary sensory area is assumed to be unaffected by other primary sensory areas or by higher order processing (e.g. emotion processing). However, a growing body of neuroscientific evidence from various areas challenges the modular view of the brain (e.g. multisensory integration; Stein & Stanford, 2008; Ghazanfar & Schroeder, 2006). Studies in the auditory domain also provide evidence against the modular architecture. It was shown that the primary auditory cortex is involved both sensory processing and interpretation; and shows learning- and memory-related processes (for a detailed account, see Weinberger, 2010). The main evidence for the direct influence of emotions on auditory processing comes from fear conditioning studies that affective-learning induces plastic changes in the auditory midbrain and cortex; and causes increased sensitivity and acuity (Armony & LeDoux, 2010).

However, behavioral evidence that emotion processing could affect representation of low-level sensory features is still sparse. The study shown in Paper I provides such evidence that negative emotion can influence perception of a basic sensory dimension; and lends further support against the modular architecture of the human mind.

The auditory system is involved in detection, analysis and comprehension of sounds. It receives input from the environment and informs the organism about the events taking place in it. In this perspective, it functions as an alarm system that scans the surroundings, detects significant events, and signals for an attention shift if necessary (Juslin & Västfjäll, 2008). This view of auditory perception makes more sense when considering the information that sounds can carry. First, sounds are well-suited to carry biologically significant information such as predator or prey presence, conspecific vocalizations, and communication signals. They also inform the individual about the events that are close or distant as well as occurring outside the reach of vision. Further, the auditory information is transformed rapidly through the nervous system, and its processing already starts at the brainstem (Rees & Palmer, 2010). Apart from these, it has also been claimed that the spatial processing in the auditory dorsal pathway has a function of guiding the visual system to a particular location of interest (Arnott & Alain, 2011), which points to the ability of auditory stimuli to carry cues for orienting. The current research outcomes agree with the alarm and orienting functions of the auditory system and the potential of emotions to influence the operation of these functions. In particular, the results from Papers II and III indicate that negative emotions can provide exogenous cues to orient spatial attention; and that sounds occurring outside the visual field induce stronger negative emotions and can be localized faster.

Further, the results point to a possible attentional bias for the space immediately behind the listeners. In particular, we found that during the dot-probe task for the trials where the same stimulus was presented in both locations, the participants were significantly faster in detecting the auditory target when it occurred behind them compared to in front of them (see Paper II). Thus, when the attention is likely to be drawn to either location due to external stimulation, it may be biased toward the rear auditory space. In Paper IV, it was found that the emotionally neutral changes taking place in a complex auditory environment could be more accurately detected when they occurred behind the participants. Finally, the results shown in Paper III provided clear evidence that both detection speed and accuracy was higher, and stronger negative emotions were evoked by the sounds occurring behind the participants compared to when they occurred in front of them. Importantly, the effect of the spatial location of the sound source on attention was mediated by emotion. Hence, all these results point to a possible attentional bias and/or differential sensory response properties depending on the region of space where the stimulus takes place. In fact, previous research found that in the absence of visual information (i.e. blindness, blindfolding, experiment in total darkness and stimulation in rear perceptual space) audiotactile integration is more likely to occur for both healthy and brain-damaged (e.g. hemineglect and extinction) human adults (for a detailed review, see Occelli et al., 2011). The audiotactile interactions are also influenced by the region of space in which they occur around an observer (i.e., stimulation in frontal space vs. rear space); and they tend to trigger rapid, defensive head and arm movements when they occur in rear-space (Farnè & Làdavas, 2002; Graziano & Cooke, 2006; Occelli et al., 2011). It has been also claimed that front and rear portions of the space could be represented by separate neural networks in humans (Viaud-Delmon, Brugger, & Landis, 2007; see also Saj & Vuilleumier, 2007). Viaud-Delmon and colleagues (2007) reported that while performing a mental imagery task, hemineglect patients failed to describe objects located on their left imaginary position. However, they were able to describe objects on both sides when they imagine they turn their back on them. The authors interpreted that the findings may stem from the fact that the lesions in the posterior parietal cortex that is involved in planning and coordinating actions would cause changes in space representation where actions can be directed (i.e. frontal space), rather than the space where no action is directed (i.e. rear space). Regardless of the exact neural mechanism, the results of Paper II, III, and IV point to a possible auditory bias toward the rear perceptual space at both attentional and emotional levels.

Finally, using a change detection paradigm, it was found that the emotional significance of sounds occurring in a complex auditory environment has an influence on the auditory attention. As discussed earlier, auditory system decomposes complex auditory input into separate object representations, which then compete for the attentional resources (Shinn-Cunningham, 2008). Change deafness (i.e. the failure to detect changes in an auditory scene) is modulated by the orientation of attention to one of those object representations (Backer & Alain, 2012). In particular, it is influenced by physical properties of the changing events (Gregg & Samuel, 2008), directed attention (Eramudugolla et al., 2005) and semantic representations of the auditory stimuli (Gregg & Samuel, 2009). The study presented in Paper IV is the first to provide clear behavioral evidence that attention allocation to separate auditory-object representations in a complex environment is modulated by their emotional significance. Importantly, it demonstrates an overall decrease in the auditory perceptual thresholds at the presence of an emotionally aversive environment. Taken together, the findings in the present thesis indicates that (1) the emotional processing is integral to the auditory perception; that is, both low-level features like the loudness perception and the processing of auditory spatial information can be modulated by the affective significance, (2) auditory-induced emotion is constructed using the available information in the auditory stimuli including the spatial dimension, and (3) emotional salience provides cues for allocation of auditory attention to relevant and significant events in the environment.

7.3 Limitations

As discussed above the current research contributes to the understanding of auditory perception and attention by considering the impact of emotional processing on them. However, it is also limited in several aspects. First, the research studies shown in the appended papers set out to investigate how emotional processing influences perception using simple lab scenarios where all the participants have to be exposed to the same procedures. This situation imposes a number of constraints on the experimental design. In each experiment, one can manipulate a limited number of experimental parameters; and for some paradigms one needs to use a relatively large number of repetitions for each experimental condition. This may cause fatigue and/or habituation effects for the participants. For instance, an obvious habituation effect was found in Paper III, where participants adapted to the stimuli and the environment within approximately three repetitions (see Paper III). Also, in a typical study, emotional responding changes during the course of the experiment. Usually, the intensity of the emotional reactions is higher in the beginning of the experiment; and it decreases later on. Therefore, the experimental blocks cannot be too long, which limits the number of auditory stimuli one can use. As discussed earlier (see Chapter 5), when using ecological sounds, in order to overcome the effect of physical differences between the sounds one may need to use a number of different sounds within each emotional category. However, the higher the number of sounds used, the longer the experiment will be. Additionally, using these simple lab tasks to study emotional influences on perception and attention may lead to the final experimental design being far from real-life situations. More realistic experimental protocols allowing the participant to move and interact with the environment can, in principle, be implemented in virtual reality settings. However, this is likely to introduce a degree of uncertainty to the experiment; and in some cases experimenter may not know for sure the cause of an effect. On the other hand, I argue that using more realistic experimental settings would let us understand more how people behave in everyday situations, despite the disadvantages of such experimental protocols. For instance, the main outcomes in Papers II and IV (i.e. negative emotions can be a cue for orientation of attention, and emotionally aversive environment increases auditory perceptual sensitivity) can be applied in a realistic experimental scenario where participants would need to orient in and navigate through a novel environment.

Another point that the current research did not take into account is the individual differences in emotional responding and attention. Previous research found individual differences in emotional responding depending on their prior knowledge, linguistic abilities, interoceptive sensitivity, and personality traits (Barrett, 2009; Barrett, Quigley, Bliss-Moreau, & Aronson, 2004; Kuppens et al., 2007; 2012). Further, existing behavioral evidence indicates that emotional influences on attention can be modulated under anxiety, depression or panic (Yiend, 2010). High-anxiety individuals seem to be more responsive and vigilant in attentional orientation to negative emotional information. The current research presented in the appended papers did not take these individual differences into account. Moreover, the sample populations in the present studies are mostly young adults in their 20s or 30s. Hence, all the outcomes may not be generalized for all age groups in society.

Finally, the measurement methods may also impose limitations on the current research. The discussion about the measures of emotion in Chapter 5 touches this particular point as well. The current studies employed self-reported emotion measures, which assume the individual capacity to introspect and be able to express the experienced feelings. Even though this assumption seems highly constraining, studies show that humans can easily distinguish pleasant and unpleasant affective states; and many, but not all, can tell if they are in a high or low arousal state (Barrett, 2006a; 2006b). Also, valence and arousal are the most replicable aspects of the emotional responding; and they can account for most of the variance in it as well (Mauss & Robinson, 2009). There are also other emotion measures one can employ, since emotions influence autonomic and somatic nervous system activity and behavioral responding (Gardhouse & Anderson, 2013; Larsen et al., 2008; Mauss & Robinson, 2009). Future research could gain from employing various emotion measures during such attentional tasks. However, one has to realize that these measures do not provide a one-to-one correlation, since they all have their unique variances (Mauss et al., 2005).

7.4 Future Research

The outcome of the research presented here contributes to the understanding of the impact of emotion on attention and perception in the auditory modality. However, it does not set out to provide an ultimate answer to the question of: *"How do the affective qualities of auditory stimuli modulate the way we attend to and perceive sounds?"* Even though the appended papers addressed this broad issue, they also generated more questions. First, as discussed in the previous section, the future research could benefit from employing several emotion measures and investigating the effects of individual differences in emotional responding and personality traits on the emotional attention. Also, the use of more realistic scenarios where participants can move around and interact with the surroundings would be beneficial.

Second, exploring multisensory interactions in similar paradigms may be a natural continuation of the current volume. One might be interested in investigating the impact of emotional information in one modality on attention and working memory in another modality. For instance, the auditory system has a function to guide the visual system to a particular location of interest (Arnott & Alain, 2011). Future research could benefit greatly by exploring the impact of emotional sounds located in different regions of space around an individual on his/her visual attention and working memory. Previous research has found that sudden and intrusive sounds can cause visual cortex activation regardless of momentary goals and intentions (McDonald et al., 2013). The timing of the visual cortex activations in this study points to the involvement of higher-order multisensory regions prior to the visual cortex. Cate and colleagues (2009) found that sustained auditory attention leads to visual cortex activation subserving the far periphery and that the peripheral visual cortex is a part of the auditory attention network. There is also evidence that indicates auditory modulation of visual cortex activity at early perceptual processing stages (Romei, Murray, Cappe, & Thut, 2009). Thus, it would be beneficial to seek behavioral evidence of the potential of emotional sounds to orient and guide vision.

Finally, the auditory scene analysis paradigms may prove useful for further uncovering the role of emotional processing in auditory perception (see; Snyder et al., 2012). Auditory scene analysis (briefly explained in Chapter 3) refers to how the auditory system organizes the complex auditory input into separate auditory objects and events (Bregman, 1999). The results presented in Paper IV indicated the role of emotional salience on orienting attention to separate auditory objects. Nevertheless, we cannot say for sure whether emotional processing plays any role in perceptual organization and formation of auditory stream segregation. Hence, the future research may benefit greatly by investigating whether this is true or not.

7.5 Application Possibilities

Knowledge about how the emotional processing influence the way we attend to and perceive sounds occurring around us has several applied uses. The two of the main arguments uttered in the current volume that the alarm function of auditory system and its role in guiding the vision to a particular point of interest, grants the auditory stimuli a great potential as warning/communication signals in Human Computer Interaction (HCI), and Virtual Reality (VR) applications. Moreover, emotions have a great impact on human behavior: they modulate perception, attention, decision-making, learning, and memory (e.g. Phelps, 2006). Humans constantly employ these mechanisms in their interactions with their surroundings. Hence, efficiency and effectiveness of media and communication applications are highly dependent on their ability to express emotions and induce emotional states in users.

Previous research has argued that the ability of sounds to evoke emotions and carry salient affective information may inform the design of effective auditory displays (Larsson & Västfjäll, 2013). Also, more efficient auditory displays and increased sense of presence in virtual environments can be reached via improved auditory spatial resolution (Västfjäll, 2003). Further, the findings presented in the current volume indicate that the auditory spatial information in relation to the observer's body can modulate emotional responses and attention (see also; Tajadura-Jiménez et al., 2010a; 2010b). Thus, the impact of stimuli located within the immediate space surrounding an observer's body (i.e. peripersonal space; PPS) on her attention and emotional reactions may prove useful to design more efficient and immersive HCI and VR applications. Briefly, PPS mediates almost every physical interaction between an organism and the external environment (Rizzolatti et al., 1997). Multisensory PPS representation is formed by integrating visual, auditory and tactile information occurring near or on the body. It has been shown that specific fronto-parietal cortical areas are responsible for the PPS representation, which helps the organism to construct a margin of safety around its body, and to select and guide actions and movement (Graziano & Cooke, 2006; Ladavas & Serino, 2008). The perceptual system is neurologically organized to distinguish near and far space representations, which means that at both neurophysiological and conceptual levels the PPS is different from the extra-personal space (Coello & Delevoye-Turell, 2007; Previc, 1998). These special properties of the PPS combined with the modulation of emotional responding and attention due to object location and movement relative to the observer's body provide a great potential for more effective and realistic interaction designs. In fact, emotions increasingly attract attention of the HCI and the interface design communities (e.g. Ho & Spence, 2013; Nasoz, Lisetti, & Vasilakos, 2010; Peter & Hebron, 2006; Picard 1997).

Finally, the work on the impact of emotional auditory stimuli around us on our attentional and processing resources may help to improve the design of everyday environments (spaces, products and media) that we all occupy. In other words, acknowledging the emotional and attentional impact the sounds may have on us should facilitate the improvement of our quality of life.

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