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Contents

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Introduction

Over the past decades the world has seen a rise in environmental noise pollution due to, for example, population growth, increasing urbanization, and mobility. Noise exposure has been associated with a variety of negative consequences (Berglund, Lindvall, & Schwela, 2000; Passchier-Vermeer & Passchier, 2000) including cardiovascular effects, sleep disturbance, and, most frequently, noise annoyance, which is the experience of nuisance and disturbance due to noise (Guski, Felscher-Suhr, & Schuemer, 1999). Research has shown, however, that noise annoyance is not solely determined by acoustic factors such as the level of the sound one is exposed to. In fact, a large part of variance in annoyance is left unexplained by acoustic factors (Bartels, Márki, & Müller, 2015; Guski, 1999; Stallen, 1999) and it has been argued that non-acoustic factors also play an important role in noise annoyance (e.g., Miedema & Vos, 1999, 2003; Stallen, 1999). Survey studies as well as experimental studies have shown that these factors include socio-emotional factors such as perceived fairness regarding the noise exposure (Maris, Stallen, Vermunt, & Steensma, 2007a, 2007b), expectations about the exposure (Crichton, Dodd, Schmid, & Petrie, 2015), affective quality of the sound one is exposed to (Västfjäll, Kleiner, & Gärling, 2003), current mood (Västfjäll, 2002), and individual difference variables. The most prominent individual difference variable explaining noise annoyance is noise sensitivity, a stable trait concerning perceptual, cognitive, affective, and behavioral reactivity towards environmental noises (Bartels et al., 2015; Crichton et al., 2015; Job, 1988; van Kamp et al., 2004; Miedema & Vos, 2003; Västfjäll, 2002)

It is not surprising that noise annoyance, which has a strong affective component, is influenced by these non-acoustic factors: Many studies have demonstrated that affective responses to environmental stimuli are influenced by state and trait factors, such as current mood (for reviews, see Bower & Forgas, 2000; Mayer, Gaschke, Braverman, & Evans, 1992; Schwarz & Clore, 2007; Västfjäll et al., 2016) and personality or temperament (e.g., Canli et al., 2001; J. J. Gross, Sutton, & Ketelaar, 1998; McCrae & Costa, 1991; for reviews, see Clore & Robinson, 2012, 2018).

Recently several researchers have argued that pre-existing affective state and affective quality inform not only the affective response to stimuli but also the perception of basic stimulus qualities (e.g., Stefanucci, Gagnon, & Lessard, 2011) such as brightness or height in the visual domain (Meier, Robinson, Crawford, & Ahlvers, 2007; Stefanucci & Storbeck, 2009) and loudness in the auditory domain (Asutay & Västfjäll, 2012; E. H. Siegel & Stefanucci, 2011). This seems to fit with insights from neuroscience that perception is not merely a passive bottom-up process but a proactive process that is informed by various sources of top-down information including affect (Barrett & Bar, 2009; O'Callaghan, Kveraga, Shine, Adams, & Bar, 2017). However, as discussed further below, the claim that affect and other top-down sources directly influence perception is not without controversy.

Like affective state and affective quality, individual difference variables such as personality and temperamental traits have also been associated with basic perception (Aron & Aron, 1997; Eysenck, 1967; Nebylitsyn, Rozhdestvenskaya, & Teplov, 1960). Specifically, it has been suggested that, due to overlapping underlying mechanisms, traits like introversion and negative affective reactivity to environmental stimuli (including noise) relate positively to sensitivity to subtle or weak perceptual stimuli (Aron & Aron, 1997; Jagiellowicz et al., 2011; Siddle, Morrish, White, & Mangan, 1969; S. L. Smith, 1968). In the auditory domain one may thus expect an association between noise sensitivity and sensitivity to weak auditory stimuli. However, it is important to note that the relation between affective reactivity to environmental stimuli and perceptual sensitivity to low intensity stimulation has been contested on theoretical and empirical grounds (Ellermeier, Eigenstetter, & Zimmer, 2001; Evans & Rothbart, 2008).

Taken together, although still debated, there are reasons to believe that non-acoustic factors such as mood, affective quality, and trait reactivity not only change affective evaluation of sounds but also change auditory perception.

To gain further understanding of the impact of non-acoustic factors on sound experience it is of interest to explore what aspects of sound perception are subject to their influence (Ellermeier et al., 2001). Therefore the current thesis addresses the question as to what extent basic auditory perception is affected by non-acoustic factors such as mood and temperament.

This question is akin to a more fundamental issue that has been heavily debated in psychology, cognitive science and philosophy: the question whether perception is penetrable by cognition (e.g., thoughts, beliefs, desires; e.g., Macpherson, 2012, 2017; Stokes, 2013), and affect (e.g., mood, affective quality and emotions; e.g., Cecchi, 2018; Machery, 2015; Raftopoulos, 2014; Vance & Stokes, 2017) or not. This is not a trivial question because the answer to it has consequences for epistemology (*Can we depend on our perception to justify our, daily as well as scientific, knowledge?*) and for the model of the architecture of our mind (*Are there separate systems for perception, cognition, and affect?*; Stokes, 2013, 2018; Zeimbekis & Raftopoulos, 2015). The debate regarding cognitive penetrability is still far from settled as evidenced by recent publications such as Firestone and Scholl's (2016) large peer commented critical review about top-down effects on perception and a special issue of *Consciousness and Cognition* (Newen, Marchi, & Brössel, 2017) devoted to the cognitive penetrability debate and its relation to predictive coding.

Before describing the approach taken in this thesis to answer the research question, the next section will first elaborate further on the *penetrability debate*. This will allow a better understanding of the theoretical and historical context and relevance of the research question. The section will describe what the debate is about. Then it will describe how the debate has developed over time, which will uncover some important nuances. The last part of the section will discuss how the research question fits within the debate and delineate the scope of the question.

1.1 Cognitive and Affective Penetrability of Perception

Nuances aside, proponents of cognitive penetrability argue that perception is partly shaped by our belief content in a direct (i.e., without mediation of action) and (semantically) coherent way (see Pylyshyn, 1999). On the other hand, opponents in the penetrability debate argue that at least part of perceptual experience or processing is informationally encapsulated (Fodor, 1983) from cognition and affect and that influence of cognition or affect on perception occurs prior to perception proper, for example, through peripheral attention or after perception proper when perceptual decisions are formed (e.g., Brogaard & Gatzia, 2015; Firestone & Scholl, 2016; Pylyshyn, 1999; Raftopoulos, 2009, 2014). Note, however, that no single definition of cognitive penetrability exists (e.g., Machery, 2015; Stokes, 2018). For example, contrary to Pylyshyn (1999), Stokes (2013) argues that the relation between the higher-level state and perception does not need to be semantic, but that it does need to be causal, internal, and mental to be called an instance of cognitive penetrability. He also argues that consequences for epistemology and cognitive architecture should be used as criteria for cognitive penetrability. For elaborate discussions about the definition of cognitive penetrability please refer to, for example, Cecchi (2014), Lupyan (2015a, 2015b), Macpherson (2012, 2017), and Stokes (2013). It is also worth mentioning that the cognitive penetrability debate can pertain to perceptual processing or to perceptual experience. The first concerns the question whether cognition influences early and/or late perceptual processes, while the latter concerns the question whether perceptual phenomenology is affected by cognition. While these questions can be regarded as two separate matters of debate (Macpherson, 2012, 2017; Pylyshyn, 1999; Teufel & Nanay, 2017) for the purpose of this brief introduction and because the debates also overlap (e.g., Firestone & Scholl, 2016; Macpherson, 2017; Stokes, 2013) these matters will be discussed together, unless explicitly indicated. For more in depth discussion about cognitive penetration of perceptual processing see for example Cecchi (2018), Pylyshyn (1999), Raftopoulos (2001, 2009), and about cognitive penetration of perceptual experience see for example Firestone and Scholl (2016), Macpherson (2012) and Stokes (2018).

History and Development of the Penetrability Debate

Over the past hundred years the dominant view in psychology (and other cognitive sciences) swung back and forth between both sides of the penetrability debate (Pylyshyn, 1999; Zeimbekis & Raftopoulos, 2015). An important contribution has been made by what has been loosely called the *New Look movement*. As a response to the then leading positivists' view that perception provided neutral information about the world, adherents to the New Look movement argued that perception was an active process partly determined by thought, memory, motivation, personality, and so forth (Bruner, 1992; Bruner & Goodman, 1947; Erdelyi, 1974). An important argument for this hypothesis was that the information received by our senses is often incomplete, quickly changing, distorted, or ambiguous and is therefore combined with available internal information to form a percept (Bruner & Goodman, 1947).

The New Look movement gained influence in psychology in the forties and fifties of the last century, producing thousands of studies suggesting that perception is shaped by internal states (see Erdelyi, 1974; Pylyshyn, 1999). A classic example is Bruner and Goodman's (1947) study showing that children judge the size of coins as larger than of equally sized gray discs and that this effect is stronger in poor than in rich children. According to Bruner and Goodman (1947) this happens because coins are more socially valuable than gray disks especially for poor children because they have a greater need for it. By the end of the fifties, however, serious methodological and theoretical flaws were pointed out in the New Look studies (Bolles, Hulicka, & Hanly, 1959; McCurdy, 1956; see Machery, 2015) and studies, including the coin size study, suffered from lack of replicability (see Machery, 2015). Results from the New Look experiments were therefore eventually discredited by many (see Erdelyi, 1974; Firestone & Scholl, 2016; Machery, 2015), but the idea that perception is theory laden remained influential, for example, in constructivists views of philosophy of science (Feyerabend, 1962; Kuhn, 1962; see Pylyshyn, 1999; Raftopoulos, 2009).

In the eighties of the last century computationalists introduced the concepts of encapsulation (Fodor, 1983), or cognitive impenetrability (Pylyshyn, 1980), of (parts of) perception, thereby differentiating between computations involved in thought and reasoning (propositional attitudes) and those involved in perception. With this idea of *non-continuity* of perception and cognition they argued against the constructivist idea that perception was (fully) theory-laden and defended the status of perception as providing justification for knowledge (Pylyshyn, 1999; Raftopoulos, 2009). Pylyshyn (1999) argued that impenetrability pertained specifically to *early vision* which he, drawing from Marr (1982), defined functionally as the part of vision that computes visual properties such as *3D shape descriptions* that do not require access to long term memory. According to Pylyshyn, effects of thoughts or beliefs on visual perception are effects on later stages of vision where decisions about the category or function of a stimulus are made (Pylyshyn, 1999). Recently Raftopoulos further elaborated on the concept of early vision and linked it to the first 100-120 ms of visual processing. This is the time it takes to complete the feedforward sweep and local recurrent processing before global recurrent processing starts in the framework of Lamme (2003; Raftopoulos, 2009, 2014). According to Raftopoulos, early vision computes low level properties including "spatial relations, position, orientation, motion, size, viewer-centered shape, surface properties, and color" (Raftopoulos, 2009). He argues that when defined in this way, no effects of cognition or affect have been observed on early vision (Raftopoulos, 2009, 2014). This claim, however, has been challenged by Cecchi (2014, 2018) who argues that penetrability of early vision has been demonstrated by brain imaging evidence for effects of high level categorization on early (60-70 ms after stimulus onset) visual processing (Gamond et al., 2011) and by evidence for top-down affective modulation of visual cortex activity at 60 to 90 ms after stimulus onset (Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Stolarova, Keil, & Moratti, 2006).

Furthermore, it should be noted that impenetrability of early perception does not exclude the possibility that later perceptual processes (i.e., involving identification and categorization) and perceptual experience are affected by cognition and affect (Cecchi, 2014). This is important for the current thesis as it focuses on non-perceptual effects that become apparent in basic (auditory) perceptual experience and performance.

In the last two decades there has been a renewed interest in studying the effects of higher states, such as beliefs, motivation, affect, and categorization on perceptual experience (for reviews, see Firestone & Scholl, 2016; Machery, 2015). The subject matter of these studies is similar to that of the New Look movement (Dunning & Balcetis, 2013) and some therefore even refer to this movement as the *New New Look* (Machery, 2015). These studies have for example reported the following findings: the belief about the typical color of an object (e.g., a banana is yellow) makes a gray scale image of that objects appear to still have that color (e.g., Hansen, Olkkonen, Walter, & Gegenfurtner, 2006; Witzel, Valkova, Hansen, & Gegenfurtner, 2011); faces classified as "black" appear darker than equally luminant faces classified as "white"; emotional arousal makes people overestimate heights (Stefanucci & Storbeck, 2009); and stimuli appear brighter after evaluating positive than after evaluating negative words (Meier et al., 2007).

The methods and conclusions of these New New Look studies have however not been without scrutiny either (Firestone & Scholl, 2016; Machery, 2015). For example, in their extensive review of studies into top-down effects on perceptual experience, Firestone and Scholl (2016) point out six pitfalls and argue that none of the studies avoid all of these (for alternative views, see open peer commentaries to Firestone & Scholl, 2016). These pitfalls are the following: (#1) being overly confirmatory; (#2) measuring effects on judgment rather than perception; (#3) being subject to task demand and response bias effects; (#4) confounding by low-level perceptual feature difference; (#5) measuring effects on peripheral attention rather than perception; (#6) measuring effects on memory rather than perception. The section on methodological issues at the end of this introduction will discuss in more detail these pitfalls and how we dealt with them in the studies presented in this thesis. Several of these pitfalls (#2, #3, #5 and #6) seem to stem from the difficulty to disentangle perceptual from non-perceptual experience, for which no clear or broadly accepted distinction exists (Teufel & Nanay, 2017). To put it in terms of perceptual processing rather than experience, these pitfalls arise due to the difficulty to pinpoint at what level in stimulus processing the effects measured by verbal report occur: at the level of, if you will, pre-perceptual, early perceptual, late perceptual, or cognitive processes (Cecchi, 2014). Therefore it has been argued that the penetrability question should be addressed using a combination of neuroimaging and electrophysiology techniques allowing measurement of the location and timing of the effect, with behavioral and psychological measures allowing interpretation of these measurements (Cecchi, 2014, 2018). As mentioned above, Cecchi (2018) argued that recent research using this approach seems to have demonstrated cognitive penetrability of early visual perception. The section below on top-down effects in the brain will discuss several other lines of neuroscientific evidence that suggest that cognitive penetrability is likely to occur. First, however, the next section will discuss the position taken in this thesis regarding the role of attention in cognitive and affective influences on perception, as this issue has been a source of confusion and controversy in the penetrability debate.

The Role of Attention

An often stated criterion for demonstrating cognitive penetrability is that effects of cognition or affect on perception cannot be otherwise explained by effects of cognition or affect on attention (e.g., Firestone & Scholl, 2016; Macpherson, 2012; Pylyshyn, 1999). This is also reflected in the fifth pitfall of empirical studies mentioned by Firestone and Scholl (2016, see above). The criterion is based on the idea that peripheral or focal attention, in a similar way as turning your head towards a different part of the visual scene, determines the input of the perceptual system, or that attention selects the *outputs* of (early) perceptual processing. Attention, then, does not influence (early) perceptual processing itself (Pylyshyn, 1999). Furthermore, when attention mediates the influence of cognition or affect on perceptual processing or experience, the influence is indirect and therefore not an instance of cognitive penetration (Macpherson, 2012). The usefulness of this criterion, however, has been contested; mainly because it seems to be based on the view (e.g., Broadbent, 1958; Deutsch & Deutsch, 1963) that attention filters information at one or various specific stages in stimulus processing (e.g., Marchi, 2017; Stokes, 2018).

Promising alternative views of attention based on recent neuroscientific and behavioral research data hold that attentional mechanisms operate throughout all levels of processing (Beck & Kastner, 2009; Duncan, 2006) including (early visual) perceptual processing (Beck & Kastner, 2009; Carrasco, 2011; Rauss, Schwartz, & Pourtois, 2011). Given that attention works at the level of (early) perceptual processing, various theorists have argued that effects of cognition on attention, particularly endogenously driven covert attention, may be regarded as cases of cognitive or affective penetration (Clark, 2016; Lupyan, 2015a; Marchi, 2017; Wu, 2017)[1]. For example, following Desimone and Duncan (1995), Wu (2017) argues that attention emerges from complex processes that resolve competition (i.e., biased competition processes). These processes can be computationally modeled using for example J. Lee and Maunsell's (2009) divisive normalization model. Attention, when understood as biased competition processes in extrastriate areas (brain areas involved in visual perception) should thus be regarded as *part of* perceptual computation. Therefore, direct influences on this type of attention, such as intention and, possibly, affective states biasing the competition, can thus be understood as penetration of perception: these states directly affect perceptual computation (Wu, 2017). Accordingly, in the current thesis we will regard effects mediated by perceptual attentional processes, such as those described by Wu, as effects on perception. It should be noted that we will not deal with the question whether this includes early perceptual processes or only late perceptual processes (for a discussion of this matter, see Raftopoulos, 2009, 2016).

Top-Down Effects in the Brain

Attentional effects are not the only top-down influences on perceptual processing demonstrated by neuroscientific studies. Influences such as task relevance, expectation, and learning, which are likely driven by central brain areas, have also been shown to modulate visual evoked activity in humans and change tuning of neuronal responses and correlations across networks in primates up to the earliest levels of cortical visual processing and even the thalamus (for reviews, see Gilbert & Li, 2013; Rauss et al., 2011). These findings

[1] It remains a matter of debate (S. Gross, 2017; Marchi, 2017) whether this argument only applies to cognitive penetration as defined without the semantic criterion (i.e., the relation between cognition and perception does not need to be semantic, such as per the definition of Stokes, 2013) or also to cognitive penetration as defined by Pylyshyn (1999) for which the semantic criterion is crucial.

challenge the traditional idea of bottom-up hierarchical processing of visual information. Instead, as Gilbert and Li (2013) suggest, cortical neurons, including those involved in perception, should be seen as adaptive processors that change function depending on the current behavioral context via input received from extensive lateral and top-down connections.

Structural neuroscience data is in accordance with this view, revealing substantial feedback connections from higher to lower areas throughout the visual system (e.g., Angelucci et al., 2002; Markov & Kennedy, 2013; Ninomiya, Sawamura, Inoue, & Takada, 2012). In fact, Markov and Kennedy (2013) suggest that feedback connections serve an even more prominent role than modulation of feedforward signals only. Recent tract tracing data in macaques (Markov et al., 2014) show segregated feedforward and feedback streams with each having high topographical precision. These neurostructural features are in line with predictive (or, generative) models of brain function (Markov & Kennedy, 2013). In these models perception is presumed to be primarily driven by signals from feedback projections, while feedforward signals serve as correction signals (e.g., Chanes & Barrett, 2016; Clark, 2013).

Early predictive models were developed as computational neural network models for visual processing specifically (e.g., Rao & Ballard, 1999). More recently, hierarchical predictive coding theory has extended these models into a unifying account of brain functioning and cognition (Friston, 2010, 2018), which is increasingly gaining influence in cognitive science (Friston, 2018). As this theory may have far-reaching implications for the penetrability debate (Newen et al., 2017), it is briefly addressed it next.

According to hierarchical predictive coding theory, perception should be regarded as "probabilistic knowledge driven inference" (Clark, 2013, p. 182). An argument for this notion is the following: Because the brain does not have direct access to the outer world, it needs to generate (and test) possible hypotheses about the causes of sensory stimulation, that is, it needs to infer the external causes of the sensory stimulation. Perception, therefore, can be understood as a "virtual version of sensory data" generated via top-down connections using high-level knowledge (Clark, 2013, p. 182).

Hierarchical predictive coding is an instantiation of the Bayesian brain hypothesis that states that the brain functions approximately according to Bayesian statistical rules (Clark, 2013; Harkness & Keshava, 2017). In the standard implementation of hierarchical predictive coding (e.g., Friston, 2005; Rao & Ballard, 1999; see Clark, 2013) higher regions in the hierarchy, representing probabilistic information about the structure of the world at more abstract level and at a larger spatial and temporal scale, provide predictions about expected activity at lower levels of the system. If a prediction does not match the activity at the level below, an error signal is sent upwards, which serves to adjust the representation at the higher level and thus also subsequent predictions. According to hierarchical predictive coding view it is thus not sensory data itself but prediction errors that are propagated upward between regions in the hierarchical system. The precision (estimated reliability) of the prediction error determines how much the higher representations are adjusted by it, and is therefore often regarded functionally equivalent to attention (Clark, 2013; Feldman & Friston, 2010; Friston, 2018; Hohwy, 2012, 2017).

As top-down predictions play such a central role in perception, predictive coding theory provides a radically different view of perception than traditional bottom-up accounts. According to some theorists hierarchical predictive coding implies that all processing is inherently context-sensitive, meaning that evoked responses will change according to the dominant top-down prediction which is informed by the current context (Clark, 2013, p. 189) and that penetrability should be seen as a "natural part of how perception works" (Lupyan, 2015b, p. 588). For a further discussion on whether or not accepting the predictive coding account entails cognitive penetrability refer to Macpherson (2017).

1.2 Taking Stock and Moving Forward

Taken together, neurophysiological and neurostructural data as well as recent predictive coding models of brain function suggest that our brain is well equipped to integrate various sources of information (e.g., perceptual, cognitive, and affective information) at all levels of processing, including perceptual levels. This adds to the plausibility of affective and cognitive penetrability of perception, including auditory perception. (Beck & Clevenger, 2016; Hackel et al., 2016; Schnall, 2017; Teufel & Nanay, 2017). It should be noted, however, that notwithstanding the enormous advancements that have been made in understanding the brain and its functioning, there is still a lot that we do not know: important aspects of hierarchical predictive coding theory still await empirical testing (for a review in the auditory domain, see Heilbron & Chait, 2018), and we are far from understanding the full structural organization of the brain (Markov & Kennedy, 2013) and how this maps to functional organization of the brain (Pessoa, 2014), let alone how this translates to cognitive and affective penetrability at a psychological level (Firestone & Scholl, 2016; Stokes, 2013). Therefore, well-controlled psychological measures are still important in the penetrability debate (Firestone & Scholl, 2016) and, as discussed above, ideally these measures should be combined with neuroscience methods (Cecchi, 2018).

Approach in the Current Thesis

While the combinatory approach suggested by Cecchi is promising, the current thesis focuses only on measures of perceptual experience and performance. This is done for the following reasons: First, the penetrability debate forms an important theoretical backdrop for understanding the relevance of the research question, but the aim of the current thesis is not to find a definitive answer to it. This thesis aims to investigate to what extent effects of non-acoustic factors such as mood and noise sensitivity on noise annoyance also pertain to basic auditory perceptual experience and performance. Specifically, the focus will be on pitch and on the ability to hear soft sounds in noise (as a measure of perceptual sensitivity) because these are traditionally regarded as straightforward auditory determined responses, similar to low level properties computed by early vision. Second, the penetrability debate has largely ignored the auditory modality. To our knowledge only one paper explicitly discusses cognitive penetrability of auditory perception (Brogaard & Gatzia, 2015). Therefore, a logical first step is to demonstrate effects on perceptual experience and performance, before determining the exact locus of these effects by using (more resource-demanding) neuroimaging and electrophysiological methods. We will however speculate about these loci and the possible mechanisms behind the effects and suggest ways to test these. Third, although non-perceptual contributions to verbal reports about perception or perceptual performance can arguably never be fully ruled out, it is possible to minimize these contributions, as the section on methodological issues towards the end of this introduction will discuss.

General Research Question and Outline

In sum, the main research question of this thesis is the following: *To what extent do affective factors such as mood and trait reactivity to environmental stimuli (i.e., noise sensitivity) influence seemingly straightforward auditorily determined responses like pitch perception and detection of sound in noise?*

The sections below will further explain the concepts relevant to the research question as well as the approach taken in this thesis to find answers to the research question. Specifically, Section 1.3 will discuss the concepts of affect, mood, affective reactivity, and evaluation, and how these concepts are used in the current thesis. Section 1.4 will explain more about (auditory) perception and specifically about pitch perception and auditory sensitivity. Here three of the four empirical chapters will be introduced. Section 1.5 will discuss the pitfalls Firestone and Scholl (2016) warned about and how the current thesis deals with these pitfalls. Here, the final empirical chapter will be introduced. The last section, Section 1.6, will provide a brief overview of the empirical chapters.

1.3 Affect

As explained above, the main question of this thesis concerns how changes in affect are associated with changes in auditory perception. To understand this question it is important to understand what we mean by affect and by auditory perception. This section will therefore explore the definition of the term affect, how it is understood from the viewpoint of different theories and how affective states can be differentiated and measured. This section will end with a discussion of the different types of affect that feature in the empirical chapters.

Defining Affect

In psychology the term *affect* commonly refers to "a mental state that is characterized by emotional feeling as compared with rational thinking" (Frijda & Scherer, 2009, p. 10). Most contemporary affective scientist will however not agree with a sharp division between affect and cognition, as their underlying cognitive and brain processes appear to be thoroughly intertwined (e.g., Fox, 2018; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Ochsner & Gross, 2008; Pessoa, 2008). Furthermore, what affect exactly entails is still a matter of much controversy (Charland, 2009; Fox, 2018), which, given the complex and experiential nature of affect, may never be fully objectively specified (Charland, 2009). Most affective scientists do agree that an affective mental state has an evaluative quality to it. In other words, it involves a positive or negative evaluation of an internal state, situation, event, object, or person. This dimension of affect is also called valence and it is generally considered the defining feature of affect. As discussed further below, arousal is often regarded as another important dimension of affect (Frijda & Scherer, 2009). While the exact definition of affect is still debated, in accordance with general practice (Fox, 2018; Frijda & Scherer, 2009), in this thesis the term affect denotes a class of mental states or processes including, but not limited to, emotion, mood, affect dispositions, and perceived affective stimulus quality.

Affect and Emotion Theories

Defining affect, and other affective concepts such as emotion, is complicated by the fact that it depends on the theoretical perspective one adheres to. One way to order these perspectives is to the degree of determinism and rigidity in the structure of the underlying process of emotion they postulate (K. R. Scherer, 2009). There are two main perspectives (Fox, 2018), each on one end of this range, with, of course, numerous theories falling in between and some that do not fit within this ordering (K. R. Scherer, 2009). On one end there are "discrete emotions", "basic emotions" or "emotions as natural kinds" perspectives (Fox, 2018; e.g., Ekman, 2003; Ekman & Cordaro, 2011; Izard, 2007; Panksepp, 1998; Panksepp & Watt, 2011). These perspectives generally (and inevitably simplified) hold that specific stimuli or situations will activate evolutionary formed processes, sometimes referred to as affect programs, that lead to a coordinated cascade of neural, physiological and behavioral responses that serve to keeping us safe and fed, finding a mate, caring for others, and so on (e.g., Cosmides & Tooby, 2000; Ekman, 2003; Ekman & Cordaro, 2011; Izard, 2007; Panksepp & Watt, 2011). Emotions in this view are functional in the sense that they help us to quickly and optimally respond in the variable and complex situations we encounter (Adolphs, 2017a; Cosmides & Tooby, 2000; Ekman, 2003). Each affect program corresponds to a specific emotion, which results in the existence of several discrete and universal emotions called basic emotions (e.g., fear, anger, joy) that can be elicited in an automatic or reflexive manner (Ekman, 2003; Ekman & Cordaro, 2011; Panksepp & Watt, 2011). Several researchers have provided lists of basic (universal and evolutionary defined) emotions (Ekman & Cordaro, 2011; Panksepp & Watt, 2011), although others argue there is not yet sufficient data to do this (Adolphs, 2017a). It should be noted that most of these theories do allow for additional more complex emotions that rely on higher level cognitive processes and provide more flexibility (Ekman, 2003; Ekman & Cordaro, 2011; Izard, 2007, 2011; Panksepp & Watt, 2011) and moods, which can be understood as more sustained states compared to emotions (e.g., Adolphs, 2017a; Ekman, 2003, see below). Still, at least by some, it is assumed that these more complex emotions built onto the basic emotions (e.g., Izard, 2007; Panksepp & Watt, 2011).

On the other end there is the constructionist (or constructivist) view of emotions (Fox, 2018; e.g., Barrett, 2017b; J. A. Russell, 2003, 2009). Very simply put, this view holds that basic emotions (e.g., anger, sadness, and fear) are not the elemental building blocks of emotion. Instead, emotions are seen as a way in which we give meaning to more basic ongoing psychological and physiological processes or components. According to Russell and Barrett (Barrett, 2006; J. A. Russell, 2003, 2009; J. A. Russell & Carroll, 1999), one such a basic component is core affect, which is the current feeling that can be described by two dimensions: pleasure and arousal (see the section on core affect below for further explanation). Furthermore, changes in a multitude of neural, cognitive and behavioral processes (e.g., "facial movement, vocal tone, peripheral nervous system change, appraisal, attribution, behavior, subjective experience, emotion regulation"; J. A. Russell, 2009, p. 1259) may accompany this feeling, although these processes do not operate in a highly coordinated fashion, predetermined order, or affect program. In fact, it is assumed that these components are continuously ongoing processes that are also running in non-emotional situations (J. A. Russell, 2003, 2009). Finally, and essential for the constructionist view, we can differentiate between various emotions or moods by means of cognitive categorization. We perceive a specific emotion in ourselves when our current state, which is the momentary state of the ongoing components, sufficiently resembles a specific stored concept, that is, when we give meaning to this state. A concept can be thought of as a mental script that specifies temporal and causal patterns of various components (J. A. Russell, 2003, 2009). In a more recent version of the theory (called the theory of constructed emotion), which puts the constructionist view in a predictive coding framework (see above for predictive coding), concepts are understood as predictions. Predictions arise from the brain's internal model of the body's external and internal world (which is built on past experiences) and predict incoming sensory information, appropriate actions and their consequences for the body's resources. When predictions match incoming information (if needed after prediction error minimization processes have updated the model), this results in a percept or experience, of such an emotion (Barrett, 2017b).

Which of these views best captures the nature of affect and emotion is still a matter of ongoing debate (e.g., Crivelli & Fridlund, 2019 vs. Keltner, Tracy, Sauter, & Cowen, 2019; Barrett, 2017a, 2017b vs. Adolphs, 2017a, 2017b; for an overview see Fox, 2018). Important for the current thesis is that proponents from both perspectives seem to deem it plausible that affect interacts with perception. According to most basic-emotions views, emotions coordinate or synchronize a large array of processes (Adolphs, 2017a; Ekman, 2003; Ekman & Cordaro, 2011; Panksepp & Watt, 2011). These processes likely include sensory perception. From an evolutionary perspective emotions configure these processes to best solve specific adaptive problems. For example, fear of being ambushed may increase hearing acuity in general or acuity for detecting fear relevant stimuli specifically, and stimuli may be perceived congruent with the current emotion (Cosmides & Tooby, 2000). Furthermore, according to Ekman (2003), a basic-emotions theorist, emotions change which information is accessible, that is, emotions guide and focus our attention in such a way that information that is not consistent with the emotion is less accessible than other information. Similarly, Izard (1977, p. 143) argues that affect, emotions, or combinations of emotions that currently occupy consciousness "filter or otherwise modify the raw sensory data transmitted by the receptors."

Russell, a prominent promoter of the constructionist view of emotion, also notes that "core affect influences perception" (J. A. Russell, 2003, p. 145). He argues that effects of core-affect on perception and cognition frequently work via the principle of mood congruency: mood congruent information is paid more attention to and is more accessible (J. A. Russell, 2003). To our knowledge Russell does not discuss whether the idea of mood congruency is applicable to explicitly affective qualities of stimuli only, or also to more basic perceptual properties. Chapter 2 will further address this issue. Furthermore, as discussed earlier, from a predictive coding point of view, which is crucial to the theory of constructed emotion, all processing, including perceptual processing, may be considered context-sensitive (Clark, 2013). Affective information contributes to this context and thereby to the likelihood of certain predictions, which in turn changes how the brain processes incoming sensory information (Barrett, 2017b) and informs conscious perception (E. Anderson, Siegel, & Barrett, 2011; Barrett & Bar, 2009; E. H. Siegel, Wormwood, Quigley, & Barrett, 2018). Thus, the theory of constructed emotion is also in line with the idea that affect interacts with perception. In fact, such interactions appear to be an integral aspect of this theory. The next sections will discuss how affective states are distinguished from each other in the current thesis.

Pleasure and Arousal

As discussed above, it is still a matter of debate whether affective states and responses are best differentiated in terms of discrete categories or continuous variations of affect along several dimensions. The dimensional approach has been shown to be particularly suitable to efficiently summarize subjective perceptions of affective quality of external stimuli and of subjective experience of affect in emotions and moods (Fontaine, 2009; J. A. Russell & Pratt, 1980; J. A. Russell & Barrett, 1999; J. A. Russell, Weiss, & Mendelsohn, 1989). In the current thesis we will follow the dimensional approach when assessing subjective affect experiences.

There are also several different notions about the number and meaning of the dimensions needed to describe the affective space (e.g., Bradley & Lang, 1994; Larsen & Diener, 1992; Osgood, May, & Miron, 1975; J. A. Russell & Pratt, 1980; K. R. Scherer, 2005). In Chapter 2 and 3 we will use the circumplex model of J. A. Russell and Pratt (1980) as a basis to differentiate between affective manipulations and subjective experiences thereof. The model describes affective states by two orthogonal bi-polar dimensions: the pleasure-displeasure (or positive-negative valence) dimension, also simply referred to as *pleasure*, and the arousal-sleepy dimension, also referred to as *arousal* or *activation* (J. A. Russell, 2003; Yik, Russell, & Barrett, 1999). The pleasure dimension concerns the hedonic value of the affective state, and the arousal dimension concerns the sensation of activation or energy mobilization (J. A. Russell, 2003). All affective states can be, albeit not completely, described by a combination of a pleasure level and an arousal level, resulting in a single point in the affect space. For example, a sad state can be described as a low pleasure, low arousal state, while an anxious state can be described as a low pleasure high arousal state.

The model is applicable to efficiently describe subjective affective experience and perception of affective quality (J. A. Russell & Pratt, 1980; J. A. Russell & Barrett, 1999). This is supported by studies showing that the factors pleasure and arousal explain a substantial amount of variance in self reported affect as assessed with various affect scales or affect words (J. A. Russell & Pratt, 1980; J. A. Russell & Mehrabian, 1977). Furthermore, the self-report affect instrument based on this model, the "affect grid", has good psychometric properties for assessing pleasure and arousal in a range of situations (affect related words, facial expressions of others, experienced affect such as current mood). This instrument is quick and easy to use, particularly when assessing the same individual repeatedly in a short amount of time (J. A. Russell, 1989). There are various other two-dimensional models of affect (Larsen & Diener, 1992; Thayer, 1996; D. Watson & Tellegen, 1985), but it has been shown that these are psychometrically equivalent, which means that the dimensions proposed by these models all describe the same two-dimensional space and can be considered alternative orthogonal rotations of the same structure (J. A. Russell & Barrett, 1999; Yik et al., 1999).

Core affect

According to Russell and Barrett (e.g., Barrett & Bliss-Moreau, 2009; J. A. Russell & Barrett, 1999; J. A. Russell, 2003, 2009), pleasure and arousal ratings of *experience* reflect a primitive affective state called core affect. Core affect is described as a simple neurophysiological state particularly apparent in moods and emotions that is consciously accessible as a single feeling of pleasure and arousal combined, although we may not be always consciously aware of it. One can often attribute the feeling to a specific cause, although core affect can also be free-floating. Core-affect can be part of more complex affective states such as moods and emotions. When assessing differences between affective states in terms of experienced pleasure and arousal, as we did in the current thesis, it is thus the core-affect aspect of mood and emotions that is being measured, at least when understood within the constructionist perspective on affect.

Types of Affect

As mentioned above, affect is used as an umbrella term for various mental states and experiences. This section will briefly explain the types of affect that are of particular interest for this thesis.

Mood

In Chapter 2 and 3 we used an affect induction method that is usually referred to as mood induction, although some refer to the same procedure as emotion induction (Siemer, 2001). The application of different terms to this procedure demonstrates the equivocal use of labels and concepts in the study of affect (Garrido, 2014). This is not surprising given that the exact definitions for the concepts emotion and mood differ between affective scientists (Beedie, Terry, & Lane, 2005) and the boundaries of the concepts are likely fuzzy (J. A. Russell, 2003). However, most affective scientist agree that, typically, where emotions are brief (seconds to minutes, but, see Frijda, 2009) and directed at a specific object or situation, moods last longer (hours to days) and lack a clear object (e.g., Beedie et al., 2005; Ekman, 1994, 2003; Fox, 2008, 2018; Frijda, 1993, 2009; Garrido, 2014; E. Gray & Watson, 2007; J. A. Russell, 2003, 2009; J. A. Russell & Barrett, 1999; K. R. Scherer, 2005; K. R. Scherer & Zentner, 2001; Siemer, 2001; Västfjäll, 2001). Most affective scientists list additional differences between moods and emotions, for example, emotions are stronger than moods (Beedie et al., 2005; Garrido, 2014; J. A. Russell, 2003, 2009; K. R. Scherer, 2005; K. R. Scherer & Zentner, 2001; Västfjäll, 2001), emotions involve much more response synchronization than moods (K. R. Scherer, 2005), moods bias cognition rather than actions (Fox, 2008, 2018), and moods are cumulative effects of shorter emotion experiences or events (Beedie et al., 2005), but these differences are not agreed upon.

The induction method used in Chapter 2 and 3 involved autobiographical memory recall or imagination of an affective event, which in some experiments was accompanied by affective music or images. Participants maintained the mood state for about 15 to 20 minutes from the onset of the induction. One could argue that the elicited affective state better fits the description of an emotion than a mood because the state was elicited by specific objects (the memories, music, or pictures) and lasted shorter than the prototypical duration of most mood states. However, the term mood induction does seem more appropriate here for the following reasons: First, the duration of the affective state while shorter than prototypical moods, was also longer than prototypical emotion episodes. Second, the affective state was the result of cumulative effect of emotional experiences, not a single object. Third, the instructions for the mood induction did not contain the word emotion and we used the term "mood" when instructing the participants to elicit the mood and maintain it over the course of the experimental tasks. Fourth, we measured the effects on auditory processing of the affective state that remained after the induction when the affect object(s) were no longer present or likely outside the focus of attention. Fifth, when assessing the experienced affect we did not ask people to report how the induction made them feel, but we asked them how their mood was at several points over the course of the experiment. Finally, the developers of the method on which the mood induction was based consistently use the term mood induction to describe the induction procedure (Eich, Ng, Macaulay, Percy, & Grebneva, 2007).

Affect disposition

In Chapter 4 we investigated the relationship between trait reactivity to environmental stimuli (e.g., noise) and measures of (auditory) perceptual sensitivity. Reactivity to environmental stimuli is largely an affect disposition. An affect disposition can be understood as one’s long-term proneness to experience a certain mood or exhibit a certain emotion when exposed to relevant circumstances (K. R. Scherer, 2005). Compared to mood and emotion, affect dispositions last much longer (K. R. Scherer, 2005). Reactivity to strong environmental stimuli is generally understood as a tendency to experience negative affect when exposed to such stimuli. Although, as argued later below and in Chapter 3, one can also have a tendency to experience positive affect when exposed to strong environmental stimuli.

Affective quality

In Chapter 5 we examined to what extent evaluative conditioning changes the affective quality of sounds (see section on methodological issues below). Affective quality, preference, affective value, or (affective) evaluation, refers to the perceived valence of a stimulus, how much it is liked or disliked (K. R. Scherer, 2005), or to the perceived potential of the stimulus to impact core affect (i.e., valence and arousal; Barrett & Bliss-Moreau, 2009; J. A. Russell, 2003, 2009). Affective evaluative responses are often considered a rudimentary and primary form of affect that can be relatively automatically elicited (e.g., Bargh, Chaiken, Raymond, & Hymes, 1996; Zajonc, 1980). However, evaluations can also arise from more deliberative processes, for example when there are conflicting evaluations regarding a stimulus or conflicts between goals and evaluations that need to be resolved (Gawronski & Bodenhausen, 2011). The difference between automatically and deliberately elicited evaluative responses is reflected in the use of implicit and explicit measures in psychology. Implicit measures are outcomes on indirect tasks, such as speeded categorization tasks, and are produced in an automatic (i.e., unintentional, resource independent, unconscious or uncontrollable) way. Explicit measures are self-reported responses of evaluative judgments that can be produced by intentional, controllable, resource demanding or conscious processes (Gawronski & De Houwer, 2014; Gawronski & Hahn, 2019). We will use both type of measures in Chapter 5 (see also the section on methodological issues below).

The current thesis focuses on how changes in affect are associated with changes in perception. Now that the use and understanding of the term affect in this thesis has been explicated, the next section will discuss how (auditory) perception is defined and measured.

1.4 Auditory Perception

This section on auditory perception begins with a discussion of the meaning of the term perception. After discussing this important but rather philosophical issue, the section will focus on the topic of auditory processing. Here pitch perception and sensitivity to sounds masked by noise will receive particular attention as these instances of auditory perception play prominent roles in the empirical chapters of this thesis. Along the way, three of the four empirical chapters (Chapter 2, 3, and 4) of this thesis will also briefly be introduced.

Defining Perception

One of the reasons that the penetrability debate, as discussed earlier, is so difficult to solve is the fact that there is no precise and generally accepted definition of perception, and, consequently also not of the divide, if any, between perception and cognition or affect. As described above, some take (early) perceptual processing and others take perceptual experience to be the subject of interest for cognitive penetration.

Furthermore, what is regarded as (early) perceptual processing of interest also varies. For example, sometimes early perception is defined purely functionally (Pylyshyn, 1999), while others relate it to processing in certain brain areas (e.g., visual cortex) and define it temporally in relation to local and global neural firing (Raftopoulos, 2009, 2014). Furthermore, some have argued that computations in perceptual (such as visual) brain areas can be understood as perception (Wu, 2017) while others seem to take only the outcome of these computations as perception (S. Gross, 2017). Yet others arrive at the conclusion that a boundary between perception and cognition may not exist. For example, Clark argues that when the mind is viewed as a cognitive predictive hierarchical processing system "the superficially clean distinction between perception and knowledge/belief dissolves at the level of neural machinery" (Clark, 2013, p. 190; also, see e.g., Hackel et al., 2016; Lupyan, 2015a).

Defining perception as perceptual experience in the context of the penetrability debate is also fraught with difficulties. According to Firestone and Scholl (2016) the definition seems simple. The fact that we are all familiar with having perceptual experiences suffices to make clear what perception is: "There is a deep sense in which we all know what perception is because of our direct phenomenological acquaintance with *percepts* – the colors, shapes and sizes (etc.) of the objects and surfaces that populate our visual experiences. Just imagine looking at an apple in the supermarket and appreciating it redness. *That* is perception" (Firestone & Scholl, 2016, p. 2). However, Firestone and Scholl also make a strong case for separating perceptual experience from perceptual decisions, judgments, attention or recognition. As mentioned earlier, separating these mental operations from perception requires looking at processes rather than at perceptual experience (Teufel & Nanay, 2017; and see section on methodological pitfalls below) and thus renders the phenomenological definition of perception of Firestone and Scholl problematic, at least in the context of the penetrability debate.

The definition of perception strongly depends on the idea about the general architecture of our brain (or mind). As already discussed above, currently the brain is often understood as a highly interconnected network, with cortical neurons, including perceptual neurons, integrating information received from bottom-up, lateral, and top-down connections (Gilbert & Li, 2013). Therefore, a graded distinction between perception and cognition and affect seems more likely than a sharp distinction (Clark, 2013; Hackel et al., 2016). Clark's description of perception is helpful here. He argues from a predictive coding standpoint that instead of a clear distinction there are "variable differences in the mixtures of top-down and bottom-up influence, and differences in temporal and spatial scale in the internal models that are making the predictions.... Lower-level (more "perceptual") ones capture or depend upon the kinds of scale and detail most strongly associated with specific kinds of perceptual contact." (Clark, 2013, p. 199). Furthermore, it is the interaction between top-down and bottom-up processes that is crucial for adaptive functioning (Clark, 2013).

In order to study possible interactions between (more) perceptual and (more) affective or cognitive processes it is necessary to make some distinction between these concepts (Marchi, 2017). Therefore, for pragmatic reasons, this thesis will follow previously made distinctions, such as the difference between bias and sensitivity in the signal detection theory framework (Green & Swets, 1966; Macmillan & Creelman, 2005) to delineate between "perceptual" and "decision" processes in the context of detection experiments. The section on methodological issues below will further explicate how this thesis distinguishes between perception and other processes. First, however, the upcoming sections will turn to auditory perceptual processing specifically, starting with the auditory stimulus.

Sound

A sound stimulus is caused by the movement of an object that creates rapid displacements of molecules in air, or another medium, resulting in fluctuations in pressure. These pressure fluctuations propagate trough the medium away from the object forming a pressure wave, which is called a sound wave when it is audible. Note that the molecules are not themselves traveling but are displaced back and forth off an equilibrium position, being pushed together (compression) and pulled away from each other (rarefaction). The resulting wave type is called a longitudinal wave because the displacement of the molecules is parallel to the direction of wave propagation (Moore, 2012). Sound waves that reach the ear set the eardrum in motion, which, after further processing in the ear and brain, ultimately allows us to hear the wave as a sound (see next section).

When an object (e.g., the diaphragm of a loud speaker) is oscillating in sinusoidal fashion, this creates a sinusoidal sound wave, which is called a pure tone or simple tone. The waveform of a pure tone (see Figure 1.1A) can be described by its frequency, amplitude and phase. The frequency is the number of oscillations, or wave cycles, per second, which is expressed in units called Hertz (Hz). The amplitude is the maximum change in pressure from the equilibrium and the phase specifies the position (in degrees) within the wave cycle for a point in space and time.

Because of their relative simplicity, both as a stimulus and in terms of auditory processing, pure tones are frequently used in auditory research. They can be easily created by computers but are rarely encountered in real life. Most sounds in our environment are much more complex and contain multiple frequencies. Many sounds that we encounter such as some of those generated by musical instruments or speech vowels are, like pure tones, periodic, that is, they consist of repeating patterns of pressure changes over time (Moore, 2012).

The rate at which the pressure pattern repeats is associated with pitch perception, as will be explained below in the section on pitch perception. It should be noted that a sound does not need to be periodic in order for it to elicit pitch perception. The section on pitch of inharmonic sounds will discuss this issue further. A sound, periodic or a-periodic, that elicits pitch perception is often referred to as a tone (Moore, 2012). The current thesis follows this terminology.

Sound waves can be represented in the time domain (i.e., pressure as a function of time) but also in the frequency domain (i.e., amplitude, energy, or power, as a function of frequency). The latter, which is also referred to as spectral representation (Wang & Bendor, 2010), can be obtained by Fourier transforming the wave from time domain to frequency domain. This is a mathematical procedure that decomposes a signal into its sinusoidal wave components (also referred to as spectral components). This transformation can be done for any (sound) wave and results are typically plotted in a magnitude spectrum, which shows frequency on the x-axis and magnitude (amplitude, energy, or power) on the y-axis (see Figure 1B,D,F,H; Moore, 2012). As will be discussed below, the brain may use both temporal and spectral representation to extract pitch. (Moore, 2012; Wang & Bendor, 2010).

The sound stimuli used in the experiments of this thesis (with the exception of Chapter 5) consist of pure tones, harmonic complex tones, and white noise. In Figure 1.1 an example of each of these sounds is shown as a waveform in time domain, and amplitude spectrum in frequency domain. As per the definition of a pure tone stated above, the spectrum of a pure tone consists of a single frequency, or to be more precise, a peak centered at a single frequency with an

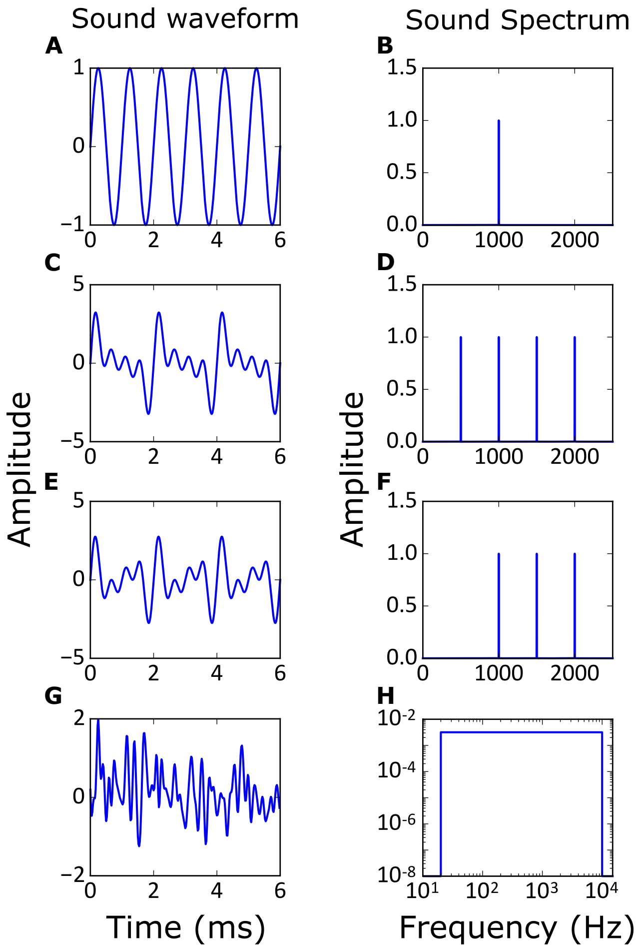

Figure 1.1: Waveform (left) and amplitude spectrum (right) representation of various sounds used in the current thesis: (A and B) Pure tone with a frequency of 1 kHz; (C and D) Harmonic complex tone consisting of the first harmonic (fundamental frequency) of 500 Hz and the second, third and fourth harmonic of 1000, 1500 and 2000 Hz respectively; (E and F) Missing fundamental harmonic complex tone composed of the second, third and fourth harmonic of 1000, 1500 and 2000 Hz respectively; (G and H) White noise limited to frequencies between 20Hz and 10 kHz.

infinitesimally small width. This is shown as a single line in Figure 1.1B. The spectrum of a harmonic complex tone consists of a fundamental frequency (also called the fundamental or first harmonic) and harmonic frequencies (also called harmonics). The harmonic frequencies are integer multiples of the fundamental frequency. Accordingly, the fundamental frequency (f_0) equals the spectral difference between adjacent harmonics and it is the lowest component of the spectrum. For example, the tone in Figure 1.1D has an f_0 of 500 Hz and the second, third, and fourth harmonic have frequencies $2f_0$, $3f_0$, and $4f_0$, that is, 1000, 1500, and 2000 Hz respectively. As can be seen in Figure 1.1C, the wave of a complex harmonic tone has a periodicity equal to T=$1/f_0$. When f_0 is not physically present in the signal, which can be seen in Figure 1.1E the periodicity in the waveform still equals the missing $1/f_0$. Such a complex tone can be referred to as a missing fundamental harmonic complex tone (Moore, 2012; Wang, 2013; Wang & Bendor, 2010) and can occur in the environment when harmonic complex sounds, such as certain speech or music sounds lose spectral information on their way to our eardrum (Wang & Bendor, 2010). Finally, white noise, which is perceived as a hissing sound, has a continuous spectrum, that is, it has equal amplitude at all frequencies. The waveform of white noise exhibits random fluctuations of pressure over time, as shown in Figure 1.1G. Figure 1.1H shows the spectrum of white noise limited to frequencies between 20Hz and 10 kHz. In this thesis we limit the spectrum for white noise to this range between 20Hz and 10 kHz for practical reasons. White noise is a typical example of an a-periodic sound, but note that there are also a-periodic sounds that do contain a discrete number of frequency components.

As mentioned, the amplitude of sound can be expressed as pressure change. However, since the range of pressure that humans can hear is very large, it would be impractical to use pressure change to specify the magnitude of a sound. Instead, sound level in decibel is used. A decibel (dB) is the logarithm of a ratio of quantities such as pressure. It relates to pressure as follows:

$$dB = 20log_{10}(\frac{P_1}{P_0}), \tag{1.1}$$

where P_1 stands for sound pressure of the sound stimulus and P_0 is a chosen reference pressure. Usually the reference pressure is chosen to be 20 μPa (micro pascal), which this thesis will follow. The use of this reference is indicated by the letters SPL which stand stands for sound pressure level, for example, 50 dB SPL (Moore, 2012). Now that the acoustical concepts relevant for the current thesis have been defined, the next section will briefly discuss how and where sound waves are translated into electrical pulses and further processed in the brain.

The Auditory System

When fluctuations in air pressure of a sound stimulus reach the ear they travel through the ear canal and subsequently set the eardrum in motion. The eardrum is connected to the ossicles (three little bones) in the middle ear that amplify and transfer the motion to the inner ear where it is transduced into an electrical signal. The inner ear contains the cochlea, which is a coiled tube that consists of several canals filled with fluid and membranes extending along the length of the cochlear tube including the basilar membrane and tectorial membranes. The movement of the ossicles sets the membranes in motion, which causes auditory receptor cells, called inner hair cells, on the basilar membrane to bend against the tectorial membrane. This triggers an action potential in auditory nerve fibers synapsing with the hair cells. The auditory nerve fibers carry this signal into the brain. The sound signal is then processed at various subcortical stations (the cochlear nucleus, superior olivary complex, the lateral leminiscus, inferior colliculus, and medial geniculate nucleus in the thalamus) before it reaches the cortex (for more thorough overviews of the auditory system, see Felix, Gourévitch, & Portfors, 2018; McDermott, 2018; Moore, 2012; Musiek & Baran, 2020). A substantial amount of spectral, temporal and spatial feature extraction already takes place in these subcortical structures (for a review, see Felix et al., 2018). Further processing of the sound is carried out by the primary auditory cortex, which is located in Heschl's gyrus in the temporal lobe and in the secondary auditory areas, or belt areas, adjacent to it. Neurons in these areas are generally responsive to more complex features than subcortical neurons. Interestingly, particularly given the current research questions, these areas do not only receive auditory information but appear to integrate information from other senses and processing in these areas is modulated by, among other things, attention, perceptual and behavioral context, and inner states such as arousal (King, Teki, & Willmore, 2018; Kuchibhotla & Bathellier, 2018). Furthermore, in addition to the auditory cortex, also numerous other cortical areas are involved in auditory perception (Musiek & Baran, 2020; Tsunada, Liu, Gold, & Cohen, 2016).

The processing pathway from the ear into the cortex is referred to as the auditory afferent system. There is also an auditory efferent system, which runs almost the same trajectory but opposite to that of the afferent system all the way down to the cochlea (Delano & Elgoyhen, 2016; Musiek & Baran, 2020). It has been suggested that these top-down connections modulate afferent signals and proposed functions of the efferent system include auditory attention (Slee & David, 2015), cross-modal attention (Bowen et al., 2020; Delano, Elgueda, Hamame, & Robles, 2007), increasing signal to noise ratio (D. W. Smith & Keil, 2015) and predictive coding (Malmierca, Anderson, & Antunes, 2015). Modulations of neural activity occur throughout the auditory pathway, even at the level of sensory transduction in the cochlea (for a review, see Terreros & Delano, 2015). For example, it has been shown (in chinchillas) that selective attention to visual stimuli modulates sensitivity of the cochlea to sound (Delano et al., 2007). Given the various modulatory roles ascribed to the the efferent system, this system may thus possibly play an important role in affective modulation of auditory processing. However, this suggestion remains speculative as our understanding of the function of the auditory efferent system is still in its infancy (Delano & Elgoyhen, 2016; King et al., 2018; Musiek & Baran, 2020).

The next sections will discuss in more detail two aspects of auditory perception that this thesis will address, namely, pitch perception and sensitivity to sounds masked by noise. Where relevant it will be discussed how the auditory system operates in these specific instances of auditory perception.

Pitch Perception

Pitch has been defined as the perceptual attribute that makes it possible to order sounds from low to high (ANSI, 1994; in Moore, 2012). Others, however, consider this conception too broad and define pitch in a more narrow sense as the "attribute of sensation whose variation is associated with musical melodies" (ASA, 1960; in Plack & Oxenham, 2005a, p. 1).

Perception of pitch or of pitch change is useful in our everyday life. It not only allows us to hear melodies in music, but it is also important for hearing intonation (Cruttenden, 1997; Ladd, 2008) and picking up emotional arousal and attitude in speech (Bänziger & Scherer, 2005; Guyer, Fabrigar, & Vaughan-Johnston, 2019; R. L. C. Mitchell & Ross, 2013). In tonal languages, such as Mandarin, Swedish and Yoruba, it is even used for understanding differences in lexical meaning (Hyman, 2001; Yip, 2002). Furthermore, our ability to hear pitch is crucial to segregate sounds sources in the auditory scene (Carlyon & Gockel, 2008; Darwin, 2005).

It is important to emphasize that pitch is a perceptual quality and not a physical attribute of sound (Plack & Oxenham, 2005b). Our auditory system, as explained below, needs to *extract* pitch from the spectral or temporal information in the sound (Oxenham, 2013b; Plack & Oxenham, 2005b). Generally, pitch is positively related to the repetition rate of a sound stimulus. For a pure tone the repetition rate is equivalent to its frequency, hence the pitch of a pure tone relates to its the frequency. However, the exact shape of this relationship has been debated (R. J. Siegel, 1965; Stevens, Volkmann, & Newman, 1937; for reviews see Moore, 2012; Plack & Oxenham, 2005b). Traditionally, pitch of harmonic complex tones is taken to correspond to the f_0 of the tone (de Cheveigné, 2005; Moore, 2012; Zwicker & Fastl, 1999), although, as will be discussed later, additional pitch dimensions based on spectral properties instead of periodicity have also been proposed (de Cheveigné, 2005; McPherson & McDermott, 2018; Smoorenburg, 1970).

Interestingly, if the fundamental frequency component is very weak or physically missing from a complex harmonic tone, or when it is masked by noise, a pitch equal to the pitch of the fundamental frequency can still be perceived from this tone (Licklider, 1954; Schouten, 1938; Seebeck, 1841; Smoorenburg, 1970). This phenomenon reflects that we are able to extract the fundamental frequency pitch from the harmonics. The percept of the missing fundamental has also been called virtual pitch (e.g., Terhardt, 1974), low pitch (e.g., Thurlow & Rawlings, 1959), residue pitch (e.g., Schouten, 1940), or periodicity pitch (e.g., Plomp, 1967).

Pitch cannot only be perceived from tones but also from noise bursts presented with temporal regularity. The repetition rate of these bursts determines pitch height and can be matched in pitch to pure tones with the same frequency as the repetition rate (Burns & Viemeister, 1976, 1981; Pollack, 1969). The same pitch can thus be heard from sounds with very different spectral properties but similar periodicity.

Theories of pitch perception

Historically there have been two major theories of pitch perception (each with several elaborations): the place theory (e.g., Helmholtz,1870/2009) and the temporal theory (e.g., Schouten, Ritsma, & Cardozo, 1962; for an overview of historical developments, see de Cheveigné, 2005). Generally, according to place theories the frequencies of sound are signaled by the locations of the neurons excited by this sound. This mechanism starts in the cochlea, which can be regarded as a bank of band pass filters, also called auditory filters. Here, different frequencies maximally displace the basilar membrane at different locations due to gradually changing mechanical properties along the length of the membrane (von Békésy, 1980; Greenwood, 1990; Olson, Duifhuis, & Steele, 2012; Wilson & Johnstone, 1975). Consequently, specific frequencies excite hair cells at specific locations on the basilar membrane, which in turn excite specific auditory nerve fibers (Narayan, Temchin, Recio, & Ruggero, 1998; Robertson & Manley, 1974; I. J. Russell & Sellick, 1977). These neurons each have a characteristic frequency, or best frequency, at which they are most sensitive, that is, the frequency at which their (sound level) threshold for firing is lowest (Kiang, Watanabe, Thomas, & Clark, 1965; for a review, see Meyer & Moser, 2010). The spatial organization of frequencies is called tonotopic organization (Clopton, Winfield, & Flammino, 1974) or tonotopy (Saenz & Langers, 2014). Tonotopic organization has been found throughout the auditory system in humans and other species, at least up to the primary auditory cortex (Elberling, Bak, Kofoed, Lebech, & Sœrmark, 1982; Formisano et al., 2003; Gardumi, Ivanov, Havlicek, Formisano, & Uludağ, 2017; Langers & van Dijk, 2012; for reviews, see Clopton et al., 1974; Saenz & Langers, 2014). According to place theories, pitch is derived from the spatial pattern of excitation that a sound produces (Oxenham, 2013b, see below for further discussion).

Temporal theories postulate that frequency is represented by the temporal pattern of neural firing (Oxenham, 2013b). The idea is that auditory neurons spike only at a certain phase of the stimulus' waveform, which is called phase locking (Rose, Brugge, Anderson, & Hind, 1967). The time intervals between the spikes are integer multiples of the period of the wave. Single neurons can only fire up to a limited amount of pulses per second due to restrictions such as the neural refractory period. Firing of a single neuron can thus not fully follow stimuli with higher frequencies. However, the pooled responses of a group of neurons that fire phase locked to a stimulus will show bursts of firing at higher frequencies (Rose et al., 1967; Tasaki, 1954; Wever & Bray, 1930).

Neurophysiological studies in animals showed evidence for phase locking in the auditory nerve up to 3-5kHz, depending on the species (Galambos & Davis, 1943; Johnson, 1980; Rose et al., 1967; Tasaki, 1954, for a review, see Heil & Peterson, 2015). The upper limit of phase locking does however decrease at each stage going up the auditory pathway (for an overview, see Wang, Lu, Bendor, & Bartlett, 2008). Phase locking has been found in the auditory cortex but only up to about 250 Hz (in guinea pig; Wallace, Shackleton, & Palmer, 2002) and spike rate coding of periodicity start to outweigh stimulus synchronized coding in the auditory cortex for stimuli with a repetition rate above 40Hz (in marmoset monkeys; Lu, Liang, & Wang, 2001; Wang et al., 2008). This means that for higher frequencies most stimulus synchronized temporal codes as carried by the auditory nerve have to be translated into spike rate codes along the way to the cortex, although it is still unclear how this exactly happens (Walker, Bizley, King, & Schnupp, 2011; Wang et al., 2008).

There is still debate about the extent to which temporal and place representations in the auditory system contribute to perception of pitch, although it appears that both theories are needed to explain various psychophysical findings

(McDermott, 2018; Moore, 2012; Oxenham, 2013b). For reviews about research findings supporting either place or temporal mechanisms for pitch perception of pure tones we refer to the discussion in (Moore, 2012; Oxenham, 2013b). For pitch perception of complex tones also place and temporal mechanisms have been proposed, although it is more accurate to label the major theories as spectral and temporal models. The next section briefly discusses these theories.

Pitch mechanisms for complex harmonic sounds

According to spectral models (e.g., Goldstein, 1973; Terhardt, 1974), also referred to as pattern recognition models, the pattern of frequencies of the partials in a complex sound is extracted and matched against a set of pitch templates to find the best matching pitch (de Cheveigné, 2005; Moore, 2012). These models only work for resolved partials (Goldstein, 1973). Partials are resolved when their frequencies are sufficiently far apart so that they excite separate places on the basilar membrane (i.e., they fall in different auditory filters) and do not interfere with each other. This is only the case for low order harmonics, which is up to about the first 10 harmonics depending on the exact definition of resolvability used (for a review, see Plack & Oxenham, 2005b). Note that the way in which the frequency of the partials is extracted is not necessarily specified in spectral models: either place or temporal mechanisms can be used (Goldstein, 1973), hence the name place models may be misleading.

A problem for spectral models is that pitch can also be heard (although less salient) from complex tones that only consist of unresolved harmonics (Houtsma & Smurzynski, 1990; Kaernbach & Bering, 2001). Temporal models can account for this. Because unresolved harmonics interact within a cochlear auditory filter, the timing of the basilar membrane vibration and thus the neural firing reflects the period of the complex tone (Schouten, 1970). Most temporal models make use of autocorrelation analysis to extract these periodicity cues reflected in the phase locked neural firing (e.g., Licklider, 1951; Meddis & Hewitt, 1991).

Pitch perception appears to be different for resolved and unresolved harmonics. This is reflected in findings that pitch perception based on low numbered harmonics is more salient and accurate than based on high numbered harmonics (Houtsma & Smurzynski, 1990; Shackleton & Carlyon, 1994). To account for these differences dual mechanisms have been proposed: For deriving pitch from resolved harmonics, spectral mechanisms are used, while temporal mechanisms are used for pitch extraction from unresolved harmonics (Bendor, Osmanski, & Wang, 2012; Shackleton & Carlyon, 1994). However, the existence of these two separate mechanisms is still a matter of debate (Carlyon, 1998; Gockel, Carlyon, & Plack, 2004; Meddis & O'Mard, 1997; also, see Oxenham, 2013b).

Pitch of inharmonic sounds

The previous sections discussed pitch as perception of periodicity and described mechanisms for the estimation of f_0. However, there are also other pitch cues, such as the lower edge of the sound spectrum, shifts in the spectral pattern, and average spectral density (McPherson & McDermott, 2018; P. Schneider et al., 2005). In a series of experiments McPherson and McDermott (2018) used inharmonic stimuli to show that (relative) pitch perception can also be based on these cues. The inharmonic stimuli used in these experiments were created by randomly jittering the components of harmonic sounds. This procedure renders a sound aperiodic and thus no single f_0 can be derived from it. Participants performed various pitch tasks with the harmonic and inharmonic sounds. These experiments demonstrated that inharmonicity did not impair the performance of tasks concerning detection of the direction of pitch change between two complex tones and in music and speech. According to McPherson and colleagues, participants used shifts in the spectrum instead of f_0 to determine pitch shift direction. For completeness, it should be noted that performance on pitch tasks involving judgment of pitch intervals or recognition of voices was hampered by inharmonicity and thus depended on f_0 estimation. McPherson and colleagues conclude that f_0 is only one of several aspects of acoustic information used in pitch perception. Which cue is most important may depend on the task at hand.

Conflicting and ambiguous pitch shifts

Because pitch perception can depend on several cues it is possible to design sounds that contain incongruent or ambiguous pitch information. A compelling example of ambiguous acoustic information is provided by the 'Laurel-Yanny' sound file that caused Internet uproar in the late spring of 2018. Different people heard the exact same (poor quality) synthetic voice clip in a very different way. Some heard the voice saying 'Laurel', while others were sure the voice said 'Yanny'. The sound file likely contained cues for 'Laurel' as well as for 'Yanny' due to compression distortions that occurred when the file was created. Listeners may have either accentuated the high frequencies or the low frequencies in the file causing them to highlight different cues. For example, they may have interpreted one of the crucial cues as either the third formant of \ɔ\ in 'Laurel' or the second formant of \i\ in 'Yanny' (Bosker, 2018; Pressnitzer, Graves, Chambers, de Gardelle, & Egré, 2018), where formants are peaks in the sound spectrum caused by vocal tract resonance and each vowel has a specific formant pattern (Fant, 1960). Interestingly, listeners were generally very certain about their percept (Pressnitzer et al., 2018).

The 'Laurel-Yanny' phenomenon is a remarkable demonstration of the fact that the same acoustic input can be perceived in qualitatively different ways. This has also been demonstrated when pitch cues provide conflicting information about pitch shift. For example, pitch of missing fundamental complex harmonic tones can be either perceived as a chord of the spectral components or as the missing fundamental frequency. Tone pairs can be constructed in such a way that the missing f_0 changes in one direction from the first to the second tone, while the spectral components (f_{sp}) change in the opposite direction. The pitch shift of a single tone pair can thus be heard as upwards but also as downwards depending on the cue that is used (Ladd et al., 2013; Laguitton, Demany, Semal, & Liégeois-Chauvel, 1998; P. Schneider et al., 2005; Seither-Preisler et al., 2007; Smoorenburg, 1970). Which cue is dominant in the percept of the pitch shift depends partly on stimulus parameters but also on individual differences in listening preference (Ladd et al., 2013; P. Schneider et al., 2005; Seither-Preisler et al., 2007; Smoorenburg, 1970). For listeners who are not purely basing their percept on f_{sp} or on or f_0 the pitch shift can be ambiguous, at least for some tone pairs (P. Schneider & Wengenroth, 2009).

Other studies using tone pairs with ambiguous or incongruent pitch shifts suggest that pitch shift perception in these cases depends on context and top-down influences. For example, Lin, Imada, Kuhl, and Lin (2018) recorded brain activity while listeners judged pitch shift of congruent and incongruent tone pairs that were created by having tone chroma[2] move in one direction and tone height[3] in the same or opposite direction respectively. When participants judged pitch shifts of incongruent shifts in tone chroma and tone height compared to congruent pitch shifts, activity in frontal brain areas increased, presumably reflecting involvement of top-down processes (Lin et al., 2018).

Furthermore, a study by Chambers et al. (2017) showed strong influence of (auditory) context on pitch shift perception. Chambers and colleagues used pairs

[2]Tone chroma refers to the equivalence perceived for tones that are separated by one or more octaves, that is, having octave relationship. An octave is a doubling in (fundamental) frequency. Tones with the same chroma have the same place and denomination (e.g., C) in the musical scale. Tone chroma can be understood as a dimension of pitch in addition to tone height.

[3]Tone height refers to dimension of pitch that is monotonically related to the (fundamental) frequency of a tone (Bachem, 1950; Lin et al., 2018).

of Shepard tones. The specific tone pair construction[4] in this experiment made it equally likely to hear the pitch going half an octave down or half an octave up from the first to the second tone. The tone pairs were preceded by one or multiple context tones. The preceding tones biased the perception in such a way that the perceived pitch shift was in the direction that contained the frequency of the preceding tones. This effect is likely explained by auditory binding. The bias was strong, up to almost 100% of the responses were consistent with the context in some conditions, and relatively long lasting, biasing effects lasted up to 32s after context presentation.

Taken together, these studies show that the same acoustic stimulus can be perceived differently depending on various factors. It is a demonstration that also auditory perception is highly subjective and that the brain actively interprets the acoustic information it receives. As mentioned, the latter is an important feature because our senses generally provide us with incomplete or distorted information about the environment, leaving the brain with the task to disambiguate this incoming information (Kersten & Yuille, 2003; McClelland, Mirman, Bolger, & Khaitan, 2014). It may be expected that in cases where a stimulus contains conflicting or ambiguous information perception will be most strongly influenced by preexisting knowledge and affect (Dunning & Balcetis, 2013; Klink, van Wezel, & van Ee, 2012; McClelland et al., 2014). Therefore, sounds with conflicting pitch cues are a good starting point to explore the influence of mood on the perception of pitch shift, a basic auditory feature.

Effects of mood on pitch shift perception (Chapter 2)

Interestingly, mood is often associated with pitch height, as is nicely reflected in observations of Dutch cellist Pieter Wispelwey: *I see some faces in the first row. I play the Sarabande and see the facial expressions change with each note. I play a high note and I see hope in the eyebrows, I go down and I see them looking sad* (Wispelwey, 2012, September 9). Research studies confirm that pitch or pitch shift direction is associated with affect. High pitch or up-going pitch shift is generally associated with positive affect, and low pitch or down-going pitch shifts with negative affect (Collier & Hubbard, 2001; Friedman, Neill, Seror, & Kleinsmith, 2018; Horstmann, 2010).

[4] Shepard tones are composed of harmonic components with octave relationships. In the experiment of Chambers et al. (2017), the frequency intervals between the harmonics of the first and the harmonics of the second tone of the pair was half an octave (i.e., six semitones), therefore each component of the first tone was halfway in between two of the components of the second tone.

Various theories suggest that the association between affect and perceptual dimensions can be bidirectional (S. W. S. Lee & Schwarz, 2012; Slepian & Ambady, 2014; Weger, Meier, Robinson, & Inhoff, 2007). This may mean that our current mood impacts the pitch shift we perceive, especially when the pitch shift is ambiguous. In order to test this idea, in Chapter 2 we explored to what extent happy and sad mood informs pitch shift judgment of tone pairs with conflicting f_{sp} and f_0 pitch cues. We expected that, if mood informs ambiguous pitch shift perception, listeners in a happy mood are more likely to judge ambiguous pitch shifts as up-going than sad listeners, who are more likely to judge these shifts as down-going.

Sensitivity to Sounds Masked by Noise

The previous paragraphs focused on pitch perception and how mood may affect this basic auditory property. Another, perhaps even more basic, feature of hearing is our ability to detect weak sounds. The auditory threshold is the lowest sound level that is still detectable and reflects sensitivity of the auditory system. The absolute threshold of hearing measures the level of a pure tone that is just audible in silence (Moore, 2012). The threshold varies with frequency in a U-shape function, with lowest thresholds between 2 and 4 kHz (Fletcher & Munson, 1933).

Masking

In daily life we seldom hear sounds in silence. Often there are various background noises such as people talking, music playing, and noises from machines or traffic that hamper the audibility of the sound we are interested in. The phenomenon that the audibility threshold of a sound is increased by another sound is called masking (ANSI, 1994; in Moore, 2012). There are various types of masking. A distinction is made between simultaneous and non-simultaneous masking. In non-simultaneous masking the mask occurs either immediately after or before the signal, also known as backward and forward masking respectively (Moore, 2012). In simultaneous masking conditions, however, the masking sound and signal are presented simultaneously. Simultaneous masking can further be divided into energetic and informational masking. Energetic masking results from overlap in the excitation patterns to the signal and the noise at the level of the cochlea and auditory nerve (Moore, 2012; Oxenham, Fligor, Mason, & Kidd, 2003). Or, to put it differently, energetic masking occurs when the signal and the noise both fall within the same cochlear auditory filter. Informational masking, on the other hand, is often described as masking that cannot be explained by energetic masking, thus, that is not due to spectral overlap between the mask and the signal (e.g., Leek, Brown, & Dorman, 1991; Pollack, 1975; C. S. Watson, Kelly, & Wroton, 1976). Instead, informational masking can occur because the signal and masker are confused, for example due to deviation from expectations about the signal or unpredictability of the masker (Moore, 2012; Oxenham et al., 2003; C. S. Watson, 2005).

Performance on non-simultaneous masking tasks or simultaneous informational masking tasks is generally found to be more susceptible to individual differences and cognitive modulation than performance on simultaneous energetic masking tasks (Oxenham et al., 2003; Strait, Kraus, Parbery-Clark, & Ashley, 2010). For example, lower thresholds in backward masking conditions (Strait et al., 2010) and in informational masking conditions (Oxenham et al., 2003) are associated with musical experience, while the threshold under simultaneous energetic masking conditions is not related to musical experience (Oxenham et al., 2003; Strait et al., 2010). Backward and informational masking may thus depend on more central processes than energetic masking (Oxenham et al., 2003). Therefore, to be able to make a stronger case for penetrability of low level auditory processing by non-acoustic factors we focused on potential effects of non-acoustic factors such as mood or individual difference variables on the masked auditory threshold under simultaneous energetic masking conditions. In this thesis the terms *masked auditory threshold* or *sensitivity to masked sounds* will refer to a situation of simultaneous energetic masking.

Mechanisms of simultaneous energetic masking. Although the exact mechanisms of simultaneous energetic masking in humans are still not known (Oxenham, 2013a) and neural correlates of sensitivity to masked sounds have been found throughout the auditory system (e.g., Christison-Lagay, Bennur, & Cohen, 2017; Delgutte, 1990), simultaneous energetic masking can be largely explained at the level of the basilar membrane in the cochlea (Moore, 2012; Recio-Spinoso & Cooper, 2013). While it is still an open question to what extent the cochlear response, and, in turn, the masked auditory threshold, is susceptible to top-down effects (Oxenham, 2013a), it is not implausible that top-down effects occur. Animal studies showed the existence of efferent pathways from higher centers of the brain all the way to the cochlear hair cells, which may modulate cochlear responses (D. W. Smith, Aouad, & Keil, 2012). Furthermore, animal studies have also shown that higher auditory centers can further modulate the signals coming from the cochlea at various stations in the afferent auditory system for example by gain control mechanisms (Dean, Harper, & McAlpine, 2005; Rabinowitz, Willmore, Schnupp, & King, 2011; B. L. Robinson & McAlpine, 2009) and rapid reshaping of neuronal receptive field (Fritz, Elhilali, David, & Shamma, 2007). Thus, there are various plausible mechanisms through which modulation of auditory sensitivity to sounds masked by noise might occur.

Mood and sensitivity to masked sounds (Chapter 3)

Studies in the visual domain have shown that current affective state induced by brief exposure to fear cues modulates perceptual sensitivity to affectively neutral stimuli (Bocanegra & Zeelenberg, 2009; T.-H. Lee, Baek, Lu, & Mather, 2014; Phelps, Ling, & Carrasco, 2006). In addition, E. H. Siegel and Stefanucci (2011) found that individuals in an anxious mood, compared to a neutral mood, inflated their judgments of loudness, another basic auditory perceptual quality, of short affectively neutral tones. Furthermore changes in affective state have been associated with changes in neuromodulators such as dopamine (DA; Ashby, Isen, & Turken, 1999), norepinephrine (NE; Aston-Jones, Rajkowski, Kubiak, Valentino, & Shipley, 1996), and serotonin (5HT; R. L. C. Mitchell & Phillips, 2007), which in turn may be involved in rapid adaptations in tuning in the auditory cortex (Fritz et al., 2007).

Given the, possibly affect induced, plasticity in the auditory system and the effects of affective state on visual sensitivity and loudness, it seems plausible that auditory sensitivity, as measured by the masked auditory threshold will also be modulated by affective state. Here it should be noted that the studies on affective modulation of visual sensitivity or loudness judgment only compared perception between anxious and neutral states. Consequently, it cannot be concluded from these studies whether the effects found were due to the pleasure or the arousal dimension of affect or a combination of both. In Chapter 3 we explored to what extent mood modulates masked auditory sensitivity. To this end we compared the masked auditory threshold between participants in four different moods: anxious (low pleasure, high arousal), sad (low pleasure, low arousal), happy (high pleasure, high arousal) and calm (high pleasure, low arousal). This comparison allowed us to study the effects of the pleasure and arousal dimension of mood on auditory sensitivity to sounds masked by noise.

Trait reactivity and sensitivity to masked sounds (Chapter 4)

The masked auditory threshold measures sensitivity to weak sounds in noise. As discussed at the beginning of this introduction, the relationship between trait sensitivity to weak stimuli and trait (affective) reactivity to strong environmental stimuli has been a matter of dispute. Some claim that the two traits are independent (Ellermeier et al., 2001; Evans & Rothbart, 2008), while others argue for one trait underlying both sensitivity and reactivity (Aron & Aron, 1997; Jagiellowicz et al., 2011; Siddle et al., 1969; S. L. Smith, 1968).

As Chapter 4 will review, the empirical evidence regarding the relationship between sensitivity to weak stimuli and reactivity is contradictory. The neurobehavioral framework of the Predictive and Reactive Control Systems (PARCS) theory (Tops & Boksem, 2010; Tops, Boksem, Quirin, IJzerman, & Koole, 2014) may provide means to elucidate this relationship. PARCS theory distinguishes two types of trait reactivity to strong stimuli: punishment reactivity and reward reactivity. Individuals with high punishment reactivity have low tolerance for strong stimulation such as noises, light flashes, and odors, and a tendency to experience negative affect from it, while individuals with high reward reactivity have a tendency to derive pleasure from strong stimulation. This distinction allows for a more fine-grained analysis of the relation between sensitivity to weak stimuli and reactivity to strong stimuli compared to previous studies, which only focused on reactivity as punishment reactivity to strong stimulation.

According to PARCS theory reactive temperament (or reactivity) is characterized by dispositional bias towards reactive brain systems, which control behavior in a momentary fashion through feedback from the continuous stream of external stimuli. Reward and punishment reactivity therefore have in common that both contribute towards a reactive temperament. Furthermore, according to PARCS theory, reactivity is also reflected in increased allocation of resources to processing relevant weak stimuli. At first glance, PARCS theory thus predicts a positive association between sensitivity to weak stimuli and punishment reactivity and between sensitivity to weak stimuli and reward reactivity. However, reward and punishment reactivity also oppose each other because each reflects a different action orientation (approach or avoid). Therefore, PARCS theory also predicts that reward and punishment reactivity are negatively associated. Consequently, due to this opposing relationship each type of reactivity may statistically suppress the relation between the other type of reactivity and sensitivity to weak stimuli. This means that the association between sensitivity to weak stimuli and punishment or reward reactivity to strong stimuli may only show up when the reactivity measures are controlled for each other.

In Chapter 4 we examined this expected suppression effect to better understand the dependencies between perceptual sensitivity to weak stimuli (in general and in the auditory domain in particular), and reactivity to strong stimuli. We, again, measured auditory sensitivity as the masked auditory threshold, while sensitivity to weak stimuli in general and punishment and reward reactivity to strong stimuli were measured using scales from the Adult Temperament Questionnaire (Evans & Rothbart, 2007).

1.5 Methodological Issues: Avoiding Pitfalls where Possible

So far this introduction discussed the issue of penetrability of perception and specified what aspects of penetrability of auditory perception this thesis will focus on. As mentioned above, Firestone and Scholl (2016) listed six pitfalls that research into top-down effects on perception (or the penetrability of perception) should avoid. The current section will discuss these pitfalls and how we took those into account. The pitfalls will be discussed in the order in which they are addressed in the chapters of this thesis. The discussion of these pitfalls will also provide further insight into the methods we have used in our studies and will lead to the introduction of Chapter 5. In addition, this section will provide some comments to the pitfalls that will not be explicitly addressed in the experiments presented in the current thesis.

It should be noted that frequently, albeit often implicitly, a distinction is made between perception, judgment, and response (e.g., in Firestone & Scholl, 2016). Even though the existence of such a clear distinction is debatable and depends on one's view of how the mind is organized (e.g., Clark, 2013; Heekeren, Marrett, & Ungerleider, 2008; Lavender & Hommel, 2007), to follow Firestone and Scholl (2016), the discussion of the first two pitfalls will be organized according to this distinction. First, the next section, on demand and response bias effects, will address the possible discrepancy between judgment and response that may confound results (pitfall #3 in Firestone & Scholl, 2016). Second, the subsequent section, on measuring effects on judgment rather than perception, will delve into the distinction between perception and judgment (pitfall #2 in Firestone & Scholl, 2016).

Task Demand and Response Bias Effects (pitfall #3)

According to Firestone and Scholl (2016), many findings that have been interpreted as cognitive or affective penetration of perception may instead be explained as effects of demand characteristics, and particularly of task demands. Other response biases may also lead to a discrepancy between the actual judgment and the response that participants provide. The sections below will first focus on demand characteristics and will then address several other response biases and how these can be avoided or controlled.

Task demand

Demand characteristics are cues, for example from the experimental context, experimenter, or task, that inform the participant about the purpose and hypothesis of the experiment and that influence how the participant responds in the experiment (Orne, 1962). Participants may try to behave according to, or opposite to, what they think is the experiment hypothesis (Orne, 1962). This threatens the validity of the experiment. Firestone and Scholl argue that studies with an obvious manipulation and only one perceptual measurement are particularly vulnerable to task demand effects. They mention as examples studies that found an effect of wearing a heavy backpack on slant estimation (Bhalla & Proffitt, 1999) or of fear of height on height estimation (Stefanucci & Proffitt, 2009). A discussion about the validity of these particular studies is not within the present scope, but it is important to explore how effects of task demands can be abated. In their recommendations for future studies Firestone and Scholl (2016) suggest the following three solutions to avoid effects of task demands: (1) Use non-transparent manipulations (2) Use indirect measures (3) Ask subjects about the experiment (e.g., what they think is the hypothesis and what strategies they used). The next paragraphs describe how we applied these suggestions in the studies presented in the empirical chapters of this thesis.

As discussed above, in Chapter 2 and 3 we tested the effects of mood on perception. The mood induction technique we used required active involvement of the participants to change their mood in a genuine and reliable way and to sustain this state during the testing phase (Eich et al., 2007). Therefore it was not possible to use a non-transparent manipulation in these experiments. Furthermore, in Chapter 2 we were interested in the participant's perceptual experience. In line with the warnings of Firestone and Scholl we did not use a single measurement but multiple measurements of this experience. However, since we had to rely on self-report, it was clear to the participant what experience (pitch shift) we were interested in. Because we used a rather transparent manipulation and relied on direct measurement of the perceptual experience we could not exclude demand effects in Chapter 2. Therefore, as per the third solution of Firestone and Scholl, we asked participants directly after the experiments to describe the hypothesis they thought we were testing. We excluded data from participants who were aware of the hypothesis.

In Chapter 5, which will be introduced shortly, we used an indirect measure (second solution suggested by Firestone & Scholl, 2016) in addition to direct self-report to minimize effects of demand characteristics. Specifically, to measure evaluations of sounds we employed an affective priming task (APT), which is a speeded categorization task that makes no explicit reference to evaluating the stimulus of interest, but one's evaluation of the stimulus can be inferred from performance on this task (Gawronski, 2009; Gawronski & Hahn, 2019). Participants supposedly have little (at least less than on self-reports) deliberate control over the outcome on such a measure, which makes it suited to minimize the demand problem (De Houwer, 2003; Gawronski, 2009).

Response bias

Firestone and Scholl (2016) also mention that many studies into cognitive and affective penetration are plagued by various other response biases that reflect a discrepancy between the actual judgment of the perceptual quality and the response provided by the participant (i.e., the expression of this judgment). Unfortunately Firestone & Scholl do not elaborate on this topic. Nevertheless, minimizing the effects of response bias is crucial for studies that require people to give judgments about the quality or magnitude of subjective experience (e.g., brightness, tone height, positive affect, personality traits), as these measures are prone to effects of response bias (Paulhus, 1991; Philbeck & Witt, 2015; Poulton, 1979).

Moreover, effects of response bias are of particular concern when the aim is to measure effects of affect on perceptual judgments because it has been shown that affect can prime response selection. This priming effect is referred to as affective mapping effect. Affective mapping effects appear to be independent from the type of muscle movement necessary for the response but do depend on the meaning of the response, which is for example determined by how the response option is labeled (Eder & Rothermund, 2008; Lavender & Hommel, 2007). For example, Eder and Rothermund (2008) asked participants to categorize the affective value of affective stimuli by bending the arm to pull a lever or extending the arm to push a lever. The pull and push responses were labeled by words that have a positive or negative connotation. The pull response was either labeled as moving the lever *downward* (negative connotation) or pulling it *towards* oneself (positive connotation) and the push response was either labeled as moving the lever *upward* (positive connotation) or *away* from oneself (negative connotation). The results confirmed the hypothesis that the responses with labels that had the same connotation as the stimulus were faster than responses with labels that had non-matching connotation, independent of whether a push or pull movement was made. This research clearly demonstrates that responses can be biased towards response options with connotations that match the affective meaning of previously presented stimuli. In the current thesis the term response selection bias is used to refer to this type of bias. When responses are recorded with response options that have affective connotations, response selection biases may confound the effects of affective stimuli or preexisting affective state on perceptual judgments. To be able to make statements about the effect of affect on perceptual judgment, it is thus crucial to disentangle the meaning of the response option from the (affective) meaning of the perceptual judgment. This was an important issue in Chapter 2 where participants reported how they experienced the pitch shift of tone pairs. They judged for each tone pair whether the pitch went upward or downward from the first to the second tone of the tone pair. Because the response labels "Upwards" and "Downwards" may have a positive and negative affective connotation respectively (Eder & Rothermund, 2008), using these labels to indicate pitch shift may confound any effect found of mood on pitch shift judgment. To be specific, participants in a happy state may have a bias towards an "Upwards" response option and participants in a sad state may have a bias towards a "Downwards" response option, regardless of their actual pitch shift perception. This type of bias may show up in responses especially when participants experience indecision regarding their percept (García-Pérez & Alcalá-Quintana, 2011), which may happen for some ambiguous stimuli used in the pitch shift task of Chapter 2 (P. Schneider & Wengenroth, 2009). A potential response selection bias may thus confound a relationship between mood and pitch shift perception bias. Therefore in Chapter 2 we explicitly investigated the presence of a potential mood induced response selection bias and took measures to control for it in case it occurred.

Furthermore, subjective assessments are prone to various other types of response bias. For example, on questionnaires participants may be inclined to give extreme rather than moderate responses (or vice versa) irrespective of the content of the items (Bachman & O'Malley, 1984; Mõttus et al., 2012; Paulhus, 1991). Additionally, questionnaire outcomes may be influenced by social desirability bias which is the case when participants try to give a good impression of themselves and modify their answers accordingly (Furnham & Henderson, 1982; Paulhus, 1991). Also judgments of sensory magnitudes have been shown to depend on various response biases. Examples are transfer biases, where responses depend on stimuli and responses presented previously, and response range biases, where responses depend on the range of stimuli presented during the experiment (see Marks & Gescheider, 2002; Poulton, 1979). These various response biases would be of particular concern for studying effects of affect if different affective manipulations impact these biases differently. Some studies indicate that this, at least for certain judgments, may be the case for desirable responding (Paulhus & Levitt, 1987) and extreme responding (Paulhus, 1991; Paulhus & Lim, 1994). Specific research as to whether this is the case for bias in judgments of sensory magnitudes appears to be lacking (Philbeck & Witt, 2015).

Response biases can be diminished in various ways: for example, by emphasizing to participants that honest answering is important and that data will be anonymously processed (against social desirability bias; Paulhus, 1991), using only two response options (against extremity bias; Paulhus, 1991), only asking one perceptual judgment per person (to avoid sequential effects; Poulton, 1979), and providing anchoring on the scale used for the strongest and weakest stimulus (to diminish certain types of range bias; Marks & Gescheider, 2002; Poulton, 1979). However, many of these approaches also have their downside and it is difficult to fully exclude the possibility that response biases have occurred (Paulhus, 1991; Philbeck & Witt, 2015; Poulton, 1979). Alternatively, in some cases performance based measures can be used to measure the construct of interest. This is what we did in Chapter 3 and 4 and it will be further explained in the next subsection.

Measuring Effects on Judgment Rather Than Perception (pitfall #2)

Firestone and Scholl (2016) note that even if reports of participants reflect the participants' genuine beliefs about changes in a perceptual quality, these beliefs (and thereby the reports) could reflect changes in judgment rather than perception. They argue that many studies that claim to show effects of cognition or affect on perception may actually only show effects on judgment. While effects on judgment can be interesting in themselves, such effects of cognition or affect on other cognitive processes are rather uncontroversial. Therefore, Firestone and Scholl stress that studies into top-down effects on perception should be able to tease apart perception and judgment, for example by using performance based measures of perception. Teufel and Nanay (2017) appear to share this view. They differentiate (following Kingdom & Prins, 2010) between performance based and appearance based psychophysical tasks. Performance based tasks measure how well an observer performs on a task. Examples are tasks measuring perceptual sensitivity, such as the threshold of hearing. Appearance based tasks, on the other hand, cannot meaningfully provide a measure of how well an observer is doing on the task, but these tasks aim to provide a measure of how a stimulus appears, that is, what the apparent magnitude of a certain stimulus quality is. Examples of appearance based tasks are measurements of perceptual biases due to context effects (e.g., apparent line length in the Müller-lyer illusion; apparent brightness of a gray patch on a light gray or on a dark gray background as measured in an asymmetric brightness matching experiment) and many scaling tasks (Kingdom & Prins, 2010). Teufel and Nanay (2017) argue that for appearance based tasks it is notoriously difficult to disentangle perceptual bias from decisional or response bias (also, see Morgan, Dillenburger, Raphael, & Solomon, 2012; Morgan, Melmoth, & Solomon, 2013; Storrs, 2015), which seems to parallel the difficulty of discriminating perceptual experience from non-perceptual experience. For example, in most standard psychophysical tasks perceptual bias will show up in the same outcome variable (e.g., the criterion, or mean of the psychometric function[5]) as decision or response biases (Morgan et al., 2012, 2013; Witt, Taylor, Sugovic, & Wixted, 2015). In Chapter 2 we attempted to measure perceptual bias rather than performance and the measure therefore suffers from the same problems as most appearance-based measures. Indeed, even though we controlled for potential biases in response selection in Chapter 2 we could not exclude the possibility that participants (consciously or unconsciously) adopted a more lenient criterion for judging pitch shift as upwards than as downwards in a happy state compared to a sad state or vice versa (see Voss,

[5]The psychometric function referred to here is derived from tasks where the observer is presented with one stimulus per trial and needs to decide after each trial which one of two mirror opposite stimuli was presented. Examples of such stimuli are up vs. down displacements in a Vernier task or left vs. right motion of a random dot stimulus. Stimulus strength or magnitude varies per trial. The proportion of choices for one stimulus (e.g., proportion "right" choices) is plotted as function of the signed stimulus strength, that is, one stimulus type has more negative values when stronger (e.g., when motion coherence increases for the left direction), while the other has more positive values when stronger (e.g., when motion coherence increases for the right direction). Perceptual bias, due to experimental manipulations (e.g., attention, adaptation, or context manipulations) should be reflected in a horizontal displacement of the psychometric function (Morgan et al., 2012).

Rothermund, & Brandtstädter, 2008). Therefore, perceptual judgment outcomes may be found to differ even when perceptual evidence was the same. Although there have been some recent promising attempts to minimize decisional bias for some specific appearance based tasks (Morgan et al., 2013), in Chapter 3 and 4 we will not attempt to measure perceptual bias but use a performance-based task measuring auditory sensitivity to curtail possible contamination by non-perceptual bias.

Signal detection theory

The distinction between perception and judgment, also referred to as sensory data or evidence, and decision formation is present in most models of perceptual decision-making (e.g., Gold & Shadlen, 2007; Green & Swets, 1966; Heekeren et al., 2008; Kelly & O'Connell, 2015; Krantz, 1969). An influential model of (perceptual) decision-making is Signal Detection theory. This formal model of decision-making, developed in the 1950s, provides a means to study whether effects of a particular variable are on (perceptual) sensitivity or on the decisions criterion used (Gescheider, 1985; Green & Swets, 1966; Kingdom & Prins, 2010; Macmillan & Creelman, 2005; McNicol, 2005; Swets, Tanner, & Birdsall, 1961). More recent, and currently more dominant, sequential analysis models of decision-making build heavily on SDT. However, in contrast to SDT, these models allow perceptual evidence to accumulate over time, accounting not only for decision outcomes but also for reaction times (Forstmann, Ratcliff, & Wagenmakers, 2016; Gold & Shadlen, 2007). Yet, SDT is nowadays still frequently used in various fields of psychology including perception research (see Wixted, 2020). It provides a helpful framework to discuss the distinction between perception and decision[6]. SDT was specifically developed to understand detection and discrimination in perception, although since its inception it has been applied to many more situations (e.g., memory research, medical diagnosis, weather forecasts; Wixted, 2020). Because this thesis is concerned with auditory perception, the following introduction to SDT will, however, discuss the theory as applied to detection in perception. Note that while detection can have a more general meaning, the focus here is on detection of the presence as opposed to the absence of a stimulus, and specifically on the threshold of detection of weak auditory stimuli in noise (as measured in Chapter 3 and Chapter 4). The purpose of introducing SDT here is to enable a better

[6]But see Witt et al. (2015) for important limitations regarding the distinction of perceptual bias and decision/response bias when applying SDT to discrimination task. This will be discussed further in the general discussion (Chapter 6) of this thesis.

understanding of the distinction between perceptual sensitivity and decision criterion. Therefore the description of the theory will be somewhat simplified and far from complete. Also, the mathematical aspects of the theory are outside the scope of this introduction. There are several excellent general texts on SDT that explain this at various levels of detail: Gescheider (1985); Kingdom and Prins (2010); Macmillan and Creelman (2005); McNicol (2005). Furthermore, unless different citations are provided, the information about SDT presented below comes from these sources.

Crucially, SDT assumes that, because the system is noisy, signals are always detected against a background of internally or externally generated noise. In a signal detection task the amount of evidence provided by the senses will therefore fluctuate from trial to trial not only due to presence or absence of the signal but also because of noise. The observed evidence on each trial can thus be understood as a sample drawn either from a probability distribution describing the random variation in *signal + noise* (*SN*) or from a probability distribution describing the random variation in *noise* (*N*). This is graphically depicted in Figure 1.2, in which it is assumed that the *SN* and *N* distributions are both normal distributions with equal variances. The observer must decide whether the evidence as provided by the senses is due to signal and noise or due to noise only or, in other words, whether the internal sensory evidence came from the *SN* or the *N* distribution. When the signal is very weak relative to the noise, the evidence will be frequently similar for signal and noise trials (distributions overlap), and the observer is likely to wrongly attribute the evidence on noise trials to the signal and vice versa.

According to SDT the observer uses a criterion (see dashed vertical lines in Figure 1.2) to make the decision. For example, when faced with a yes/no task, that is, when a participant has to decide on each trial whether a signal was present (yes) or not (no), the participant will decide "yes" when the perceptual evidence exceeds the criterion and "no" when the evidence is below the criterion. Given equal chance of signal present or absent, an ideal observer would place the criterion where the two distributions intersect (see dashed line labeled ideal criterion in Figure 1.2A). Observers, however, often use different criterion values (see dashed line labeled biased criterion in Figure 1.2B), which means they are biased towards "yes" or "no". The placement of the criterion is directly

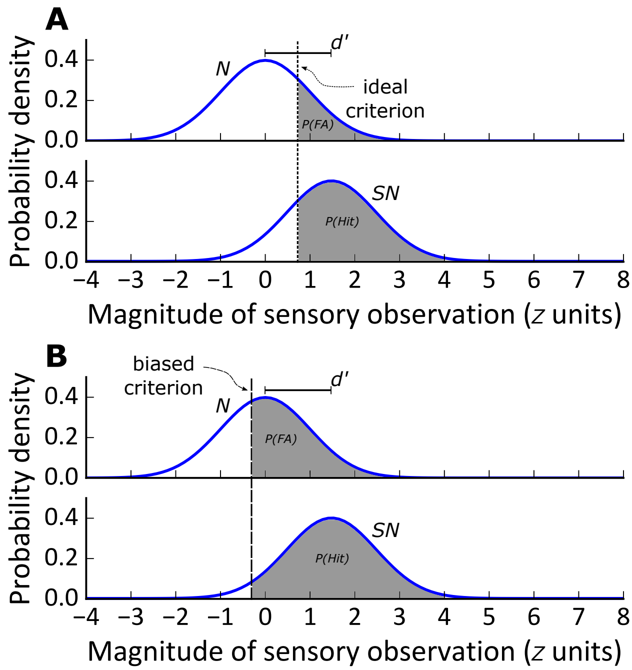

Figure 1.2: Panel A shows the *noise* (N) and *signal + noise* (SN) probability distributions describing the random variation in sensory magnitude (in z-units) in response to, respectively, noise and signal + noise trials in a yes/no task. The distance between the means of the distributions reflects d', the perceptual sensitivity. The vertical line indicates the position of the criterion the observer uses to determine whether a signal was present or not. If the observed sensory magnitude exceeds the criterion, a "yes" response is given. If the observed sensory magnitude is below the criterion this results in a "no" response. In this case the ideal criterion is depicted (in a situation where signal present and signal absent trials are equally likely to occur and the goal is to maximize the proportion correct). The shaded areas show the $P(FA)$, proportion of proportion of false alarms, and the $P(Hit)$, the proportion of hits. Panel B shows the same distributions, and thus the same perceptual sensitivity as in panel A but a more lenient criterion. This results in an increased $P(Hit)$ but also in an increased $P(FA)$ compared panel A.

related to bias[7]. For example, when the observer becomes more lenient, the

[7] This is interchangeably referred to as response bias (e.g., Jones, Moore, Shub, & Amitay, 2015; Macmillan & Creelman, 2005) or as decisional bias (e.g., Cataldo & Cohen, 2015). However, some authors explicitly distinguish (non-decisional) response bias from decisional bias depending on the cause of the bias (e.g., García-Pérez & Alcalá-Quintana, 2011), which is in line with the (debatable) distinction between judgment and response we discussed earlier. Both types of bias will show up as a shift of the criterion in a standard STD analysis of a detection experiment.

criterion is placed lower and less evidence is needed to decide that the signal was present and the observer has a bias towards "yes". This will result in more correctly identified signals (which are called *Hits*) and less missed signals (which are called *Misses*) but also more falsely identified noise trials as signal trials (which are called *False Alarms*) and less correctly identified noise trials (which are called *Correct Rejections*). A change in the location of the criterion will thus change the performance of the participant, even though his or her sensitivity did not change.

Because the user needs to set an internal criterion for judging whether a signal is present or not, yes/no tasks (and other classification tasks with a single stimulus per trial) are prone to effects of bias. Criterion changes may occur unconsciously or consciously due to various reasons. For example, it has been shown that bias depends on signal probability (base-rate) and the cost and benefits of each of the decisions outcomes (payoff structure; e.g., Swets et al., 1961) in order to maximize reward, rather than proportion correct. However, criterion placement is often sub-optimal (for a review, see Rahnev & Denison, 2018). For example, people generally do not adjust their criterion enough to fully maximize reward (e.g., Maddox & Bohil, 1998). Bias has also been shown on tasks with equal chance of signal present or absent and focus on accuracy in naïve participants, possibly because they underestimate their level of internal noise (e.g., Jones et al., 2015).

When bias is present, proportion correct trials on a yes/no task is not a suitable measure for the perceptual sensitivity of the observer because proportion correct depends on the location of the criterion (Kingdom & Prins, 2010). If bias differs between experimental conditions (e.g., different moods) this will thus confound any experimental effects on perceptual sensitivity if measured as proportion correct. Instead of proportion correct, sensitivity can be computed from the proportions of hits and false alarms in such a way that it is independent from the criterion used. This measure is referred to as d'. In Figure 1.2 sensitivity is reflected in the distance between the two distributions. The further the distributions are apart, the higher the sensitivity. More specifically, d' is equal to the difference between the means of the (standardized) distributions.

"Criterion free" 2IFC task

Another solution to minimize biased task outcomes is to use a task that is less prone to bias than the yes/no task, such as the two alternative forced choice task (2AFC task). In a 2AFC task, instead of a single stimulus, two stimuli are presented per trial. In Chapter 3 and 4 we used the 2 interval forced choice task

(2IFC), which is a type of 2AFC task. In the 2IFC task observers are presented with two intervals, one containing the signal + noise, the other containing noise only. The signal interval occurs with equal probability as the first or the second interval. Observers indicate after each trial which of the two intervals contained the signal. If we again assume that the *SN* and *N* distributions are both normal distributions with equal variances, such as depicted in Figure 1.3A, the observer thus needs to decide on each trial which of the two intervals contained a sample from the *SN* distribution and which of the *N* distribution. Forced choice tasks are often regarded "unbiased" or "criterion free" (for examples in the auditory domain, see Marshall, Hanna, & Wilson, 1996; Marshall & Jesteadt, 1986) because there is no inherent difference in consequences of errors (wrongly choosing interval 1 or interval 2), as is the case for errors in yes/no tasks (false alarm or miss). As Kingdom and Prins (2010, p. 30) state it, the options "interval 1" and "interval 2" are on "equal footing".

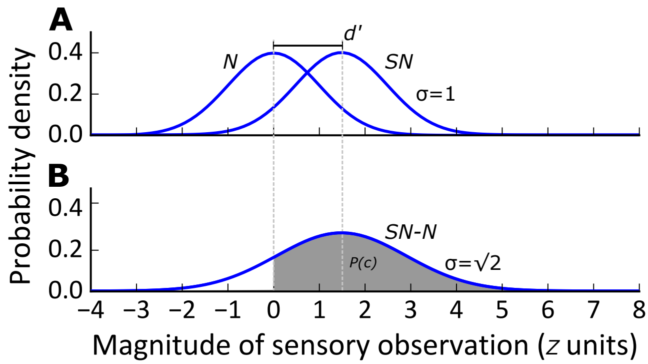

Figure 1.3: Panel A shows the *noise* (N) and *signal* + *noise* (SN) probability distributions describing the random variation in sensory magnitude (in z-units) in response to, respectively, noise and signal + noise intervals in a 2 interval forced choice (2IFC) task. The distance between the means of the distributions reflects d', the perceptual sensitivity. Panel B shows the $SN - N$ difference distribution, which is the distribution of the differences between random samples drawn from the SN and N distributions. The shaded area is the expected proportion of correct responses, $P(c)$, which is the proportion of difference scores that is greater than 0. Note that the units on the x-axis are in z-units of the N and SN distributions, that is, normalized to the standard deviation (σ) of the N and SN distributions. The standard deviation of the individual distributions in the panel A is therefore σ=1 and of the difference distribution in panel B it is $\sigma=\sqrt{2}$.

Furthermore, if the observer is not biased towards one of the intervals, the proportion correct can be used as a measure of sensitivity and can be easily transformed into a d' score. The idea is that the observer on each trial uses the simple decision rule of choosing the interval with the largest sensory evidence. The observer will thus be correct on all trials in which the signal interval indeed elicited greater sensory evidence than the noise interval. Or to put it differently, the observer will be correct when the difference in sensory evidence between the sample drawn from the SN distribution and the sample drawn from the N distribution is greater than zero. The expected proportion correct is thus the proportion of difference scores that is greater than 0. This is shown as the shaded area in Figure 1.3B, which depicts the distribution of the difference. The difference between two normally distributed variables is normally distributed with a mean equal to difference between the means and variance equal to the sum of the variance of the individual distributions. The distribution of this difference (the $SN-N$ difference distribution) given the specific d' in Figure 1.3A is shown in Figure 1.3B. The shaded area shows the probability that the difference score is greater than zero, which is the expected proportion correct. If it is assumed that the observer used the simple strategy as described above (other strategies are possible; e.g., Stüttgen, Schwarz, & Jäkel, 2011), one can easily work back from the proportion correct acquired from the performance on the 2IFC task (for one specific observer and stimulus level) to calculate the mean difference and thus d' (see for an example of such a calculation e.g., Kingdom & Prins, 2010, p. 178).

It should be noted however, that proportion correct will be an underestimation of sensitivity if the observer is biased to one of the two intervals (e.g., Jones et al., 2015; Kingdom & Prins, 2010), which is also referred to as interval bias or order bias (García-Pérez & Alcalá-Quintana, 2011). Stationary interval biases (constant inclination to choose one interval over another; Jones et al., 2015) in 2IFC tasks have been found to be absent or much smaller than stationary response biases in yes/no tasks (e.g., Jones et al., 2015; but this may not be the case for all types of stimuli; Yeshurun, Carrasco, & Maloney, 2008). However, it has recently been shown that 2IFC tasks may suffer from other biases such as non-stationary biases (e.g., the response is influenced by the previous trials; Jones et al., 2015) or response bias to one of the intervals on trials at which the participant is undecided (García-Pérez & Alcalá-Quintana, 2011). The Summary and Discussion chapter at the end of this thesis will address some of these issues again.

Despite these concerns we opted for the 2IFC task because of the need to use an adaptive method for determining the threshold, as explained below. To the best of our knowledge, at the time of testing, there were no adaptive testing methods available (neither for yes/no nor for 2IFC tasks) that allowed estimation of d' and the criterion (Klein, 2001; Lesmes et al., 2015). As the use of a 2IFC task has been frequently recommended over a yes/no tasks because it "discourages bias" (Kingdom & Prins, 2010; Macmillan & Creelman, 2005, p. 179), we chose the former.

Adaptive procedure

In an adaptive procedure stimulus levels of the signals are increased or decreased depending on the stimulus levels and performance of the participant on the previous trial or sequence of trials (Leek, 2001). An example of an adaptive procedure is the transformed up-down method in which the signal level is increased on the trial following an incorrect trial and decreased after a given number of consecutive correct trials. This results in signal levels revolving around a level at which the participant performs at a certain percentage correct. This level, which is often calculated by averaging the signal levels at reversal points (trials at which the stimulus level changed from going up to down or vice versa), is taken as the threshold level. Different rules can be used to target different percentages correct.

Because most observations are obtained around the level of interest (e.g., the 80% correct detection level) on the psychometric curve, adaptive procedures are more efficient (fast while accurate) than other classic psychophysical methods that can be used to determine the threshold. These other methods require many observations over wide range of values (e.g., method of constants) or are much more inaccurate (e.g., method of limits; Kingdom & Prins, 2010; Leek, 2001; Levitt, 1971). In Chapter 3 and 4 we used a 2IFC task combined with an transformed and weighted up/down adaptive method (García-Pérez, 1998, see Chapter 3 for further explanation). We employed this adaptive procedure to estimate the masked auditory threshold because of its efficiency. Efficiency of measurement is key when investigating effects of mood on perception, because induced moods only last for a relatively short time. Depending on the mood induction used and the task performed this has been found to be up to 20 minutes (Frost & Green, 1982; Isen, Clark, & Schwartz, 1976; Isen & Gorgoglione, 1983). Thus, to be able to measure effects of mood on the auditory threshold it was crucial that the task duration fell well within this period.

Confounding by Low-level Perceptual Feature Difference (pitfall #4)

So far this introduction has discussed processing of affectively neutral auditory stimuli and modulation by affective states or traits. Auditory stimuli themselves can also have an affective quality. Think of how you feel when you hear the screeching sound of fingers on a blackboard, the sound of an ice-cream van, the neighbor's crying baby, or your favorite song. As mentioned at the beginning of this introduction, it has been suggested that affective quality of a stimulus may inform perception of basic stimulus qualities. Also, it is often argued that affective stimuli have a processing advantage over neutral stimuli (e.g., Pourtois et al., 2004; Stolarova et al., 2006; Vuilleumier, 2005). Therefore it is also interesting to investigate to what extent the affective quality of a sound changes seemingly straightforward auditorily determined responses to it.

According to Firestone and Scholl (2016), many studies that found top-down effects of stimulus meaning (e.g., affective quality) on perception can be explained by effects of low-level feature differences. Possible confounding by low-level stimulus features is also an issue when studying affectively valued sounds (Aeschlimann, Knebel, Murray, & Clarke, 2008; Cave & Batty, 2006). For example, increased activity to affective prosody compared to neutral prosody, which is frequently reported in the right mid superior temporal gyrus (Witteman, Van Heuven, & Schiller, 2012), a voice-sensitive brain region, can be equally well accounted for by the conjoined effect of several acoustic parameters as by affective arousal (Wiethoff et al., 2008). To solve the problem of confounding there are several ways to create control stimuli matched on low-level features, but this has its difficulties, as will be discussed below. These difficulties are particularly pronounced in the auditory domain because, at least for complex sounds, there are too many low-level features to take into consideration (e.g., frequency, intensity, duration, and spectral and temporal complexity).

One approach to create control stimuli is to match an affective stimulus set to a set of naturally occurring affectively neutral stimuli on relevant physical characteristics (Aeschlimann et al., 2008). Another way is to artificially create a control stimulus for each affective stimulus by changing some features while retaining relevant physical characteristics. This can be done by using mathematical transformations of a sound that render it unrecognizable (Fastl, 2001; Fastl, Menzel, & Krause, 2006).

There are at least two difficulties with these approaches. One difficulty is to determine which physical properties are relevant to control given the measure of sensory or perceptual processing one is interested in. Often it is not exactly clear which (combination of) features determine the outcomes on this measure. For example, it is nearly impossible to equate complex sounds simultaneously on psychological loudness and physical amplitude of the sound (Moore, 2003; Owren & Bachorowski, 2007). A second difficulty with these approaches is that it is not possible to match on low-level features, when these features carry the affective quality of the stimulus (Banse & Scherer, 1996; Wiethoff et al., 2008) or determine the affective evaluation of the stimulus (Halpern, Blake, & Hillenbrand, 1986). For example, in a study investigating neural responses to baby cries, Seifritz et al. (2003) could not use amplitude envelope-matched control sounds because these were rated as similar to the baby cries on affective valence and arousal. Thus, it is difficult to determine which features of the affective stimuli should be kept equal and which should be changed in order to create suitable control stimuli.

Furthermore, there is a problem specifically related to creating artificial control sounds. Such procedures may not only take away the "affective quality" of the stimulus, they also make the sound less natural. This introduces an additional difference between the affective stimulus under investigation and the control stimulus that may explain differences on the measure of interest. The next section discusses another way to control for low-level differences.

Evaluative Conditioning (Chapter 5)

Chapter 5 proposes that a conditioning approach may offer a solution to the above mentioned problems with creating control stimuli. Conditioning allows manipulation of the affective quality of a stimulus, while its physical properties remain the same. Several studies measured brain electrical activity to simple visual (Keil, Stolarova, Moratti, & Ray, 2007; Stolarova et al., 2006) or auditory (Weisz, Kostadinov, Dohrmann, Hartmann, & Schlee, 2007) stimuli conditioned with strongly aversive or neutral stimuli (pictures). These studies did show amplification of early sensory processing of the aversively conditioned stimulus during the conditioning phase. These studies clearly demonstrate the potential of using conditioning as a tool to investigate affective influences on sensory and perceptual processing, but they have several limitations. In these studies only aversive unconditioned stimuli were used to manipulate the affective quality of the stimulus, while a complete picture of processing of affective sound should also include positive sounds. Furthermore, they lack ecological validity because artificially generated tones were used, while in our natural listening environment these types of sounds are very rare (Neuhoff, 2004).

Evaluative conditioning (EC) is a form of conditioning that changes the valence of a stimulus, in positive or negative direction (De Houwer, Thomas, & Baeyens, 2001; Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010; Levey & Martin, 1975). It has, to the best of our knowledge, not been used to change the affective quality of environmental sounds. In Chapter 5 we therefore investigated whether EC can evoke enduring changes in the evaluation of short environmental sounds in both negative and positive direction in order to explore to what extent EC is suitable to use for future studies into basic auditory perception of affective environmental sounds while effectively controlling low level-stimulus properties.

Overly Confirmatory (pitfall #1)

Firestone and Scholl (2016) argue that research into top-down effects on perception is overly confirmatory. Most of this research focuses on demonstrating the expected effects but not on demonstrating that effects do not occur when the theory predicts they should not occur. These disconfirmatory predictions are important to exclude (or demonstrate) that the confirmatory effects are driven by (non-perceptual) effects other than the theorized (perceptual) effect. Firestone and Scholl give as an example the hypothesis that negative meaning of words makes us see things darker (e.g., Meier et al., 2007). This effect should not show up when the darkness of the ink color of the word is measured by choosing a gray scale patch matching in darkness. If we see the world as darker, both the ink color and the gray patch should be darker. So, if we do observe the effect, this is likely attributable to other factors, such as demand effects.

As described above we did control for alternative non-perceptual explanations in various ways. Furthermore, because research into affective effects on auditory perception is relative uncharted territory (at least at the time the experiments were designed), we started with examining if such effects occurred.

Measuring Effects on Peripheral Attention Rather Than Perception (pitfall #5)

As discussed earlier, in the section on the role of attention in the penetrability debate, Firestone and Scholl (2016), among others, maintain that many findings of supposed effects of cognition or affect on perception can be explained as effects on peripheral attention. However, in the same section, it was also argued that attention is an integral part of perception. Therefore the stance taken in the current thesis is that effects of cognition or affect mediated by perceptual attentional processes, such as biased competition, should not automatically be rejected as case of cognitive or affective penetration of perception.

Measuring Effects on Memory Rather Than Perception (pitfall #6)

As a final pitfall, Firestone and Scholl (2016) note that performance on perceptual tasks, particularly those that involve recognition, may not only reflect perception but also memory processes. Effects on these memory processes rather than perception could thus explain any effects of cognition or affect on performance of these tasks. For example, Lupyan and Spivey (2008) found that when meaningless squiggly shapes were introduced as rotated "2s" and "5s", performance on a visual search task with these shapes as targets and distractors improved markedly compared to when these shapes were introduced as abstract shapes. Lupyan and Spivey concluded from these findings that semantic labeling improved perception of the shapes. However, since detection in a visual search task requires participants to have an active representation of the search target in working memory, it cannot be excluded that the effects of labeling took place at the level of working memory (Klemfuss, Prinzmetal, & Ivry, 2012). An effect on working memory thus provides an alternative explanation to a "true perceptual effect" for the effect of semantic labeling on visual search performance (Firestone & Scholl, 2016; Klemfuss et al., 2012). However, a similar issue as with the previous pitfall concerning attention complicates this interpretation. Memory mechanisms, like attention mechanisms, can be regarded as integral part of perception (Gerbino & Fantoni, 2016; Lupyan, 2016). In fact, various accounts of brain mechanisms underlying perceptual *experience* state that in order for a conscious percept to arise, attention and memory processes are necessary (Cecchi, 2014; Raftopoulos, 2009). Whether the memory pitfall can be applied thus seems to depend on how perception is defined. It appears to be nonsensical to require exclusion of effects on all memory processes when one is interested in top-down effects on perceptual experience if memory processes are indeed necessary for perceptual experience. Only when perception is regarded as process this pitfall may be applied. One can try to unravel which perceptual processes are affected by cognition or affect.

For the experiments in this thesis we made use of standard paradigms developed to measure auditory perception. However, responses to these tasks likely also require processes other than early perceptual processes. For example, to carry out the 2IFC task (Chapter 3 and 4) the perceptual information presented in the first interval needs to be maintained in order to compare it to the information in the second interval. This likely implies involvement of (auditory) working memory (Romo & de Lafuente, 2013; Romo & Salinas, 2003; Stüttgen et al., 2011). Since only one item needs to be maintained for the simple detection task we used in Chapter 2 and 3, working memory is probably not strongly taxed. Therefore it is unlikely that working memory is the process that limits performance (i.e., the masked auditory threshold) and effects on performance will more likely reflect effects on perceptual sensitivity than working memory. Furthermore, it has been shown that sensitivity calculated from 2IFC tasks is comparable to that calculated from other psychophysical procedures (e.g., yes/no task and 4IFC or 8 IFC task) that supposedly have different memory requirements than the 2IFC tasks (Swets, 1959). For example, in a single interval tasks, such as the yes/no task the sensory information needs to be compared to a reference stored in long term memory rather than to a stimulus maintained briefly in short term memory (Romo & Salinas, 2003). Swets (1959) showed that detectability (d') of a tone (of a specified sound level) in noise obtained with a 2IFC task is similar to that obtained with various other psychophysical procedures, including the yes/no task. Therefore performance on the 2IFC task does not seem to be strongly determined by memory processes required for the task itself. Here it should be noted that convergence between 2IFC and other psychophysical procedures is not always found and that this likely depends on stimuli, participant characteristics such as practice level and task requirements specific to the experiment (Yeshurun et al., 2008).

Furthermore, it is not exactly known what strategies participants use in a 2IFC task and which processes are involved (Yeshurun et al., 2008). Recent efforts to map neural activity to the processes leading up to perceptual decisions in detection or discrimination tasks (including representation of stimulus features, working memory and decision processes) suggest involvement of a large network of brain areas including perceptual but also frontal areas (Lemus, Hernández, & Romo, 2009; Romo & de Lafuente, 2013; Russ, Orr, & Cohen, 2008; Tsunada et al., 2016). But exactly how and where in the brain sensory inputs are translated into a decision is still a matter of ongoing research (Tsunada et al., 2016). The current thesis aims to explore to what extent seemingly straightforward auditory determined responses like pitch perception and detection of sound in noise are associated with mood or trait reactivity. Therefore, unraveling the exact mechanisms underlying performance on the 2IFC task and the ambiguous pitch task lies not within the scope of the current thesis. Our approach is to first investigate whether effects of non-acoustic factors occur on tasks that have been used in previous research to measure basic auditory perception. Depending on the results, a next step may be to delve into the exact processes underlying the task outcomes and study on which of these processes non-acoustic factors have an effect.

1.6 Brief Overview of Empirical Chapters

To recapitulate, the current thesis will focus on the associations between the following affective factors and measures of auditory perception: Chapter 2 will look at effects of mood on the perception of pitch shift direction. Chapter 3 will examine effects of mood on the masked auditory threshold (also, see Bolders, Band, & Stallen, 2017). Chapter 4 deals with the relationship between perceptual sensitivity and trait reactivity (also, see Bolders, Tops, Band, & Stallen, 2017), and Chapter 5 explores EC as a method to establish enduring changes in the affective quality of short environmental sounds (also, see Bolders, Band, & Stallen, 2012).

2

Ups and Downs in Mood and Pitch: Mood Congruency in Auditory Perceptual Judgments

This chapter is based on: Bolders A. C., Denham, S., Stallen, P. J. M., Band, G. P. H. (in preparation). Ups and Downs in Mood and Pitch: Mood Congruency in Auditory Perceptual Judgments.

It is well established that people evaluate ambivalent stimuli in a mood congruent fashion. Happy moods promote positive evaluations, while sad moods promote negative evaluations. In the current study we investigated whether mood congruency effects extend beyond evaluative judgments to auditory perceptual judgments of pitch shift. To this end, we used an ambiguous pitch task in which the change in pitch between pairs of tones can be perceived both as ascending and as descending. We compared biases in pitch shift perception on this task between listeners in experimentally induced happy and sad moods. In Experiment 1, listeners in a sad mood judged the tone pairs more often as descending compared to listeners in a happy mood. However, pitch shift judgment bias was possibly confounded with a bias in response selection. Therefore in Experiment 2 we tested and controlled for response selection bias. Findings of Experiment 2 did not support an effect of mood on response selection bias but also not on pitch shift bias. When Experiment 1 and 2 were combined into one analysis to increase power, the pattern of results provided support for an effect of mood on pitch shift judgment that cannot be attributed to bias in response selection. It should however be noted that the effect of mood on pitch shift bias depended on strength of subjectively experienced mood. Thus, although generalizability of this study remains to be demonstrated, this study showed that not only evaluative judgments but also auditory perceptual judgments can be modulated in a mood congruent fashion.

Keywords: mood congruency, auditory perception, pitch shift, affect-as-information, missing fundamental, emotion bias.

2.1 Introduction

In a happy mood, the world looks bright, people seem friendly and birds whistle merrily. In a sad mood, however, brightness may turn into gloom, a friendly smile may be mistaken for contemptuous laughter and the cheerful twittering of birds may go unnoticed. There is ample evidence that people make judgments, such as evaluations of others' behavior or life-satisfaction in a mood congruent manner (for reviews, see Bower & Forgas, 2000; Mayer et al., 1992; Schwarz & Clore, 2007). But just how far-reaching are the consequences of our mood? To shed light on this question, we investigated whether mood congruency effects extend to auditory perceptual judgments.

According to the influential affect-as-information theory (Schwarz & Clore, 1983), individuals use their current mood as information to judge how they feel about a particular object or event (Schwarz & Clore, 2007, 1983). Recent evidence suggests that pre-existing affect not only informs evaluative judgments but also visual perceptual judgments (Riener, Stefanucci, Proffitt, & Clore, 2011; Stefanucci & Storbeck, 2009). Here we explore for the first time whether the same applies in the auditory modality.

A great deal of affective information is conveyed to us via our ears; for example, by vocal expressions (de Gelder & Vroomen, 2000) and music (Juslin & Västfjäll, 2008). Therefore we hypothesize that pre-existing affect can also inform auditory perception, resulting in mood congruent influences on auditory perceptual judgments. A recent study has indeed demonstrated mood congruency effects on the evaluation of sound; music containing both happy and sad acoustic cues is judged sadder in a sad mood (P. G. Hunter, Schellenberg, & Griffith, 2011). The current study is intended to go a step further than looking at affective evaluation, by testing for mood congruency effects on pitch shift judgments, which are qualitative judgments of sound properties.

Listeners experience tone sequences ascending in pitch as more happy than sequences descending in pitch (Collier & Hubbard, 2001). Therefore, in turn, pre-existing affect may serve as information to judge pitch shift direction of ambiguous tone sequence. For example, if listeners in a sad mood use their sad feelings to determine the direction of the pitch shift, this would bias their perception towards hearing a descending pitch shift. This bias would be strongest when the pitch shift direction is ambiguous, as affect informs judgments particularly when other, more relevant, information is inconclusive or unavailable (Schwarz & Clore, 2007).

To test for mood congruent pitch shift perception we used a task in which listeners heard a pair of tones and judged whether the pitch changed in an upward or downward direction between the first and second tone (Ladd et al., 2013; P. Schneider & Wengenroth, 2009). The pitch of both of the tones was ambiguous and chosen so that the pitch shift could be perceived both as ascending and as descending. A pitch shift judgment bias was calculated and compared between listeners in experimentally induced happy and sad moods. We expected that if mood is used as information to judge the direction of the ambiguous pitch shift, then after positive mood induction pitch shift judgment would be biased towards ascending pitch shift, while after negative mood induction, pitch shift judgment would be biased towards descending pitch shift.

2.2 Experiment 1

Method

Participants

Forty-seven participants (Age: $M = 20.1$, $SD = 2.4$, $18-27$ years; 10 males) with no self-reported depression or hearing problems took part for course credit or payment (€ 5). They were randomly assigned to either a happy or sad mood condition. Data from 12 participants were not included in the analyses due to technical problems (one participant), because they were aware of the hypothesis (two participants), did not comply with the mood induction procedure (two participants), scored below 60% correct on the control task (two participants), or failed to get into the desired mood state (pleasure score during the task deviating less than one point in the desired direction from neutral mood; five participants).[1] The study was approved by the ethics committee of the

[1] In footnotes, the main analyses will also be presented including participants who had a pleasure score during the task deviating less than one point in the desired direction from neutral mood.

Institute of Psychology of Leiden University. Before the start of the study each participant gave informed consent.

Mood induction and assessment

Participants were instructed to write about a mood-appropriate event in detail and to vividly imagine it. It was emphasized that their notes would be treated confidentially. They could use an autobiographical event or an example provided to them. Participants gave subjective ratings (SR) of their momentary mood by clicking on an electronic version of the 9x9 affect grid (J. A. Russell et al., 1989). They indicated pleasure on the horizontal axis (extremely unpleasant [1] to extremely pleasant [9]) and arousal on the vertical axis (extremely low arousal [1] to extremely high arousal [9]).

Pitch tasks

In the ambiguous pitch task participants were presented with pairs of harmonic complex tones with missing fundamental frequencies. Harmonic complex tones consist of frequency components, called harmonics, which are integer multiples of the (missing) fundamental frequency of the complex tone. Correspondingly, the fundamental frequency (f_0) equals the difference in frequency between adjacent harmonics (Moore, 2012). Psychophysical studies have demonstrated that when the fundamental frequency is not physically present, the pitch of a tone can be either perceived as a chord of the spectral components (f_{sp}) or as the f_0 (Ladd et al., 2013; Laguitton et al., 1998; P. Schneider et al., 2005). The tone pairs for the task were constructed in such a way that the (missing) f_0 changed in one direction from the first to the second tone, and the f_{sp} changed in the opposite direction. This is best illustrated with an example. Consider a tone pair with tone A and B. Tone A consists of a 1000, 1500 and 2000 Hz component. The pitch of tone A can be perceived as a chord of the three component frequencies (f_{sp}) or as the f_0 (500 Hz). Tone B consists of a 1200, 1600 and 2000 Hz component. Tone B thus has a higher f_{sp} than tone A, but its f_0 (400 Hz) is lower. Listeners can perceive the sequence of these tones as either ascending or descending, depending on whether they hear the pitch of the tones as the f_{sp} or f_0. For listeners who do not have an absolute preference to hear either f_0 or f_{sp}, this gives rise to ambiguous pitch shift perception (P. Schneider & Wengenroth, 2009).

The tone pairs, based on Schneider et al. (2005), were generated in MATLAB (Version 7.12.0.635, The MathWorks Inc., Natick, MA, 2011), saved as wav files (16 bit, mono, 50kHz) and played to the participants using E-prime 2 software (W. Schneider, Eschman, & Zuccolotto, 2002). Thirty-six different tone pairs (500 ms tone duration, 10 ms ramps, 250 ms silence between tones) were generated. The tone pairs were presented twice, once in one order (AB) and once in reversed order (BA), resulting in seventy-two trials.[2]

To test pitch perception ability, a control pitch task was included (Laguitton et al., 1998) with 48 different control tone pairs. The task was equal to the ambiguous pitch task except that f_0 and the f_{sp} changed in the same direction from the first to the second tone. This allowed for classification of responses as "correct" or "incorrect".[3] All sounds were presented at a comfortable level and after the practice trials (see procedure) participants were asked if the sounds were clearly audible or if sound levels had to be adjusted. None of the participants asked for an adjustment of the sound level.

In both the ambiguous pitch task and the control task, participants looked at a white fixation cross centered on the screen, which turned yellow when a tone pair was played. After listening to the tone pair, participants indicated whether the pitch of the second tone went up or down compared to the first tone (the question asked in Dutch was: *"Gaat de toonhoogte van de tweede toon ten opzichte van de eerste toon omhoog of omlaag?*"). They indicated this by clicking with the mouse on one of two buttons labeled "Upwards" ("*Omhoog*") and "Downwards" ("*Omlaag*"), located left and right from the center on the

[2]Tones of the ambiguous tone pairs consisted of two, three or four adjacent harmonics with the frequency of the upper harmonic being either 932, 1661 or 2960 Hz. These properties were the same for both tones in a tone-pair. The lowest harmonic number (the position of the harmonic in the harmonic series counting the f_0 as first harmonic) did differ between the two tones in each pair; creating a lowest harmonic number transition from the first to the second tone that was either 2 to 3; 3 to 4; 4 to 6; 7 to 9, or vice versa. Thus, in total there were 3 (numbers of harmonics) x 3 (frequencies of the upper harmonic component) x 4 (harmonic number transitions) x 2 (tone orders) = 72 different tone pairs.

[3]Control tones were constructed based on the method described by Laguitton et al. (1998) with an adapted version of the MATLAB script. For each of the seventy-two tone pairs from the ambiguous pitch-shift task, the ratio of the missing fundamental frequencies ($f0_{ratio}$ = $f0_{Tone2} / f0_{Tone1}$) and the ratio of the frequencies of the lowest harmonic components ($fmin_{ratio}$ = $fmin_{Tone2} / fmin_{Tone1}$) was computed. Next, for each of the seventy-two ambiguous pitch-shift tone pairs two control tone pairs were created, one based on the $f0_{ratio}$ and one on the $fmin_{ratio}$. This was done in the following way: The first tone of each ambiguous tone pair also served as the first tone in the control tone pairs. For the second tone in a control tone pair the frequency of each component of the first tone was multiplied with the $f0_{ratio}$ for one set of control tones pairs and with the $fmin_{ratio}$ for another set of control tone pairs. Next, 24 tone pairs from each set were selected to serve as control tone pairs: 12 with the lowest, and 12 with the highest $f0_{ratio}$; 12 with the lowest, and 12 with the highest $fmin_{ratio}$. Thus, in total there were 48 control tone pairs.

screen. Assignment of the labels to the buttons was counterbalanced across participants. Participants also indicated how certain they were of their judgment; however, data derived from this question are not presented here.

Experimental procedure

Participants were guided to a dimly lit, quiet individual test cubicle where the experimenter explained the flow of the experiment and how to use the affect grid. After inserting the earphones (Etymotic ER-4B microPro, providing 35 dB external noise attenuation) the experimenter verified whether external sounds were attenuated. Participants were seated in a comfortable chair at 50 cm from the computer monitor, where further instructions were provided.

Participants started with two practice trials with control tone pairs not further used in the experiment. Next, they proceeded to the pre-induction pitch task followed by the mood induction procedure and the post-induction pitch task. After that, participants were instructed to change their mood back to their baseline level. Participants in the sad mood-condition received a candy to help them alleviate their mood. When participants indicated that they were ready to continue, they carried out the control pitch task, followed by questionnaires that included an open question asking the participants to write down as specific as possible what they thought the goal of the experiment was (other questions not discussed here). Throughout the experiment participants rated their mood seven times on the affect grid: at the start (SR1), after the pre-induction task (SR2), halfway (SR3) and at the end (SR4) of the mood induction procedure, after the post-induction task (SR5), after mood-recovery (SR6) and after the control task (SR7).

Results

Unless indicated otherwise, we used analyses of variance (ANOVA) or *t*-tests. Outcome measures were screened for outliers per mood group using the three interquartile range (3IQR) criterion. The interquartile range (IQR) is the difference between the third and the first quartile (which are the quartiles between which the middle 50% of the [rank-ordered] data lies). Following the 3IQR criterion, values are considered (extreme) outliers when they lie more than $3*IQR$ below the first quartile, or more than $3*IQR$ above the third quartile. No outliers according to the 3IQR criterion were detected on subjective pleasure or arousal level during the task or on pre-induction or post-induction biases (see below for further explanation of how these biases were calculated).

Subjective mood experience during the pitch tasks

Subjective arousal and pleasure level averaged over ratings obtained before and after each pitch task were calculated to indicate the experienced mood during task performance. Table 2.1 shows the average ratings and standard errors during each task. There was no significant difference in pleasure, $t(33) = 1.18$, $p = .247$, or arousal, $t(33) = -.13$, $p = .894$, between the mood groups during the pre-induction task (SR1 and SR2 averaged). During the post-induction task (SR4 and SR5 averaged) the happy group experienced more pleasure, $t(33) = 19.16$ $p < .001$, and arousal, $t(33) = 3.01$, $p = .005$, than the sad group, indicating successful mood induction. During the control task (SR6 and SR7 averaged) there were no differences in pleasure, $t(33) = 0.17$, $p = .105$, or arousal, $t(33) = 0.17$, $p = .249$, between the happy and sad group, indicating a successful return to baseline mood levels.

Table 2.1: *Average subjective pleasure and arousal ratings and standard errors during each pitch task in Experiment 1.*

Affective Dimension	Mood Induction Group	Moment of measurement		
		Pre-Induction Task M (SE)	Post-induction Task M (SE)	Control Task M (SE)
Pleasure	Happy	5.72 (0.27)	7.58 (0.20)	5.86 (0.23)
	Sad	5.32 (0.20)	2.62 (0.16)	5.29 (0.25)
Arousal	Happy	5.11 (0.28)	5.44 (0.28)	4.47 (0.31)
	Sad	5.18 (0.40)	4.03 (0.38)	5.03 (0.37)

Control task

The proportion of correctly identified (unambiguous) pitch shifts in the control task did not differ between the sad ($M = 0.90$, $SE = 0.03$) and happy group ($M = 0.91$, $SE = 0.03$), $F(1,33) < 1$. This indicates that both groups had equal pitch shift identification abilities that were well above chance level.

Test of main hypothesis: Pitch shift judgment bias

For each individual the bias in pitch shift judgment was calculated from the number of upwards (n_{Up}) versus downwards (n_{Down}) judgments as follows:

$$\text{Pitch shift judgment bias} = (n_{Up} - n_{Down}) / (n_{Up} + n_{Down}). \quad (2.1)$$

Table 2.2 shows the means and standard errors of the pre-induction and (adjusted) post-induction pitch shift judgment bias per mood group. The pitch shift judgment bias did not significantly differ between the groups at pre-induction, $F(1,33) < 1$. To test the effect of mood on the pitch shift judgment bias, a one-way analysis of covariance (ANCOVA) was conducted with the pre-induction bias added as covariate to reduce error variance. Pre-induction bias was indeed significantly related to the post-induction bias, $F(1,32) = 10.76$, $p = .003$, $\eta_p^2 = 0.25$. The assumption of homogeneity-of-regression-slopes was met as indicated by a non-significant interaction between pre-induction bias and mood, which was tested in a separate model, $F(1,31) < 1$. The ANCOVA showed that the happy group had a stronger tendency than the sad group to judge the pitch shift of the tone pairs as ascending, $F(1,32) = 4.38$, $p = .044$, $\eta_p^2 = 0.12$, $MSE = 0.029$, 95% CI[0.003, 0.240].[4]

Table 2.2: *Means (and standard errors) of pre-induction and post-induction pitch shift judgment biases and standard errors per mood group of Experiment 1.*

Pitch shift judgment bias	Mood induction group	
	Happy ($N = 18$) M (SE)	Sad ($N = 17$) M (SE)
Pre-induction pitch shift judgment bias [1]	-0.057 (0.044)	-0.051 (0.045)
Post-induction pitch shift judgment bias[1,2]	-0.008 (0.040)	-0.129 (0.042)

Notes:

1. A score of 0 indicates no bias, while a score of 1 indicates full bias towards up judgments and a score of -1 indicates full bias towards down judgments.
2. Adjusted for the pre-induction pitch shift judgment bias.

[4]When participants who had a pleasure score during the task deviating less than one point in the desired direction from neutral mood were included in the analyses the effects of mood were as follows: While numerically the happy group had a stronger tendency than the sad group to judge the pitch shift of the tone pairs as ascending, the ANCOVA showed that this difference did not reach significance, $F(1,37) = 3.07$, $p = .088$, $\eta_p^2 = 0.08$, $MSE = 0.030$, 95% CI[-0.015, 0.207]. Conclusions regarding covariate and the assumptions of the ANCOVA were the same as when the participants were excluded.

Discussion

The results of Experiment 1 are in line with the hypothesis that mood congruency effects extend to judgments of auditory qualities. As was expected, participants in a happy mood showed a greater tendency to judge tone pairs as going upwards in pitch than participants in a sad mood. However, firm conclusions cannot be drawn from these results because the way in which participants indicated the direction of the pitch shift may have introduced a confounding variable. Participants indicated whether the pitch of the second tone went up or down compared to the first tone by pressing one of two buttons labelled “Upwards” and “Downwards”. Participants in a happy state may have had a tendency to choose the “Upwards” response option and participants in a sad state may have had a tendency to choose the “Downwards” response option, regardless of their actual pitch shift perception. This response selection bias may thus have confounded the relationship we found between mood and pitch shift perception bias. Therefore, in Experiment 2 we set out to investigate the presence of mood induced response selection bias and to control for it. Because gender differences in pitch discrimination have been found (Rammsayer & Troche, 2012), only female participants were recruited for Experiment 2 in order to increase group homogeneity.

2.3 Experiment 2

Participants

Seventy participants (Age: $M = 19.2$, $SD = 1.8$, $17-27$ years; females only) with no self-reported depression or hearing problems took part for course credit or payment (€ 6.50). They were randomly assigned to either a happy or sad mood condition. Data from 16 participants were not included in the analyses due to technical problems (one participant), because they were aware of the hypothesis (one participant), did not comply with the mood induction procedure (two participants), scored below 60% correct on the control task (one participant), or failed to get into the desired mood state (pleasure score during the task deviating less than one point in the desired direction from neutral mood; eleven participants).[5]

[5] See footnote 1

Materials, mood induction, mood assessment, pitch tasks, and procedure

Materials, mood induction, mood assessment, pitch tasks, and procedure were identical to those of Experiment 1, with two exceptions. A minor difference between Experiment 1 and 2 was that in Experiment 2 both participants in the sad and the happy mood-condition received a candy after the post-induction task. This was done in order to assure that the experimenters remained blinded to the experimental conditions the participant was in until the end of the experiment.

The main difference between the experiments was the phrasing of the question regarding the pitch shift. For half of the participants the question was phrased as follows (Question 1): Was the first tone higher or lower than the second tone? (*"Was de eerste toon hoger of lager dan de tweede toon?"*). For the other half of the group the question was phrased differently (Question 2): Was the second tone higher or lower than the first tone? (*"Was de tweede toon hoger of lager dan de eerste toon?"*). All participants indicated their answer by clicking with the mouse on one of two buttons labelled "Higher" ("*Hoger*") and "Lower" ("*Lager*"), located left and right from the centre on the screen. Assignment of the labels to the buttons and question phrasing was counterbalanced across participants.

Note that for participants receiving the second question an effect of mood on response bias would be in the same direction as the hypothesized effect of mood on response selection bias. In that case response selection bias would be a positive confounding variable. For example, when answering "higher", this could be due to judging the pitch shift as going up (judging the second tone as higher), or due to a bias toward pressing the button labelled "higher". For participants receiving the second question the pitch shift bias was the reverse of the response selection bias. For example, when answering "higher" this could be due to judging the pitch shift as going down (judging the first tone as higher), or due to bias towards pressing the button labelled "higher". In this case an effect of mood on response bias would thus be in the opposite direction of the hypothesized effect of mood on response selection bias and response bias would be a negative confounding variable.

If across participants mood had an effect on pitch shift judgement but not on response selection, a main effect of mood was expected regardless of the phrasing of the pitch shift question. However, if the effect of mood was driven by response selection bias, no main effect of mood but an interaction of mood with question phrasing interaction was expected, reflecting that the effect of mood depended on how the question was phrased.

Results Experiment 2

Unless indicated otherwise, we used analyses of variance (ANOVA) or t-tests. Outcome measures were screened for outliers per mood group. No outliers according to the 3IQR criterion were detected on subjective pleasure or arousal level during the task, pre-induction or post-induction biases.

Table 2.3: *Average subjective pleasure and arousal ratings and standard errors during each pitch task in Experiment 2.*

Affective Dimension	Mood Induction Group	Moment of measurement		
		Pre-Induction Task M (SE)	Post-induction Task M (SE)	Control Task M (SE)
Pleasure	Happy	5.68 (0.20)	7.56 (0.14)	6.60 (0.20)
	Sad	5.26 (0.18)	2.48 (0.13)	5.48 (0.21)
Arousal	Happy	5.50 (0.34)	6.04 (0.29)	5.96 (0.28)
	Sad	4.66 (0.22)	3.64 (0.25)	5.10 (0.21)

Subjective mood experience during the pitch tasks

Subjective arousal and pleasure level averaged over ratings obtained before and after each pitch task were calculated to indicate the experienced mood during task performance. Table 2.3 shows the average ratings and standard errors during each task. There was no significant difference in pleasure, $t(52) = 1.57$, $p = .122$, between the mood groups during the pre-induction task (SR1 and SR2 averaged). Pre-induction arousal ratings were slightly, but significantly, larger for the happy than for the sad group, $t(52) = 2.09$, $p = .043$. During the post-induction task (SR4 and SR5 averaged) the happy group experienced more pleasure, $t(52) = 26.12$, $p < .001$, and arousal, $t(52) = 6.29$, $p < .001$, than the sad group, indicating successful mood induction. During the control task (SR6 and SR7 averaged) there were still differences, albeit smaller than during the post-induction task (see Table 2.3), in pleasure, $t(52) = 3.74$, $p < .001$, and arousal, $t(52) = 2.51$, $p = .017$, between the happy and sad group. As can be seen in the next analysis this difference was not reflected in a difference between the groups regarding performance on the control task.

Control task

The proportion of correctly identified (unambiguous) pitch shifts in the control task did not differ between the sad ($M = 0.89$, $SE = 0.02$) and happy group ($M = 0.92$, $SE = 0.02$), $F(1,50) < 1$, there was no significant effect of question phrasing, $F(1,50) < 1$, and there was no interaction between mood and question phrasing, $F(1,50) < 1$. This indicates that both mood groups had equal pitch shift identification abilities and that this did not depend on question phrasing.

Test of main hypotheses: Pitch shift judgment bias or response selection bias

The pitch shift judgment bias was calculated in the same way as in Experiment 1. The pitch shift judgment bias did not differ significantly between the groups at pre-induction, $F(1,50) < 1$, there was no significant effect of question phrasing, $F(1,50) < 1$, and there was no interaction of mood and question phrasing, $F(1,50) = 2.38$, $p = .129$, $\eta_p^2 = 0.05$. To test the effect of mood and question phrasing on the pitch shift judgment bias a two-way analysis of covariance (ANCOVA) was conducted with the pre-induction bias added as covariate to reduce error variance. Pre-induction bias was indeed significantly related to the post-induction bias, $F(1,49) = 48.65$, $p < .001$, $\eta_p^2 = 0.50$. The assumption of homogeneity-of-regression-slopes was met as indicated by non-significant interactions between pre-induction bias, mood and question phrasing, which were tested in a separate model, $F\text{s}(1,47) < 1$. As can be seen in Table 2.4, which shows the means and standard errors of the pre-induction and (adjusted) post-induction pitch shift bias, the happy group had a numerically stronger tendency than the sad group to judge the pitch shift of the tone pairs as ascending. The ANCOVA showed that this effect did not reach significance, $F(1,49) = 3.14$, $p = .083$, $\eta_p^2 = 0.06$, $MSE = 0.017$, 95% CI[−0.008, 0.134]. There was no significant interaction effect between mood and question phrasing, $F(1,49) < 1$. This indicated that effects of mood on the pitch shift judgment bias did not significantly depend on the way the question was phrased.[6]

[6]When participants who had a pleasure score during the task deviating less than one point in the desired direction from neutral mood were included in the analyses the effects of mood and question phrasing were the following: The ANCOVA showed no significant effect of mood, $F(1,60) < 1$, 95% CI[−0.051, 0.099], no significant effect of question phrasing, $F(1,60) < 1$, and no significant interaction effect between mood and question phrasing, $F(1,60) < 1$. Conclusions regarding covariate and the assumptions of the ANCOVA were the same as when the participants were excluded.

Table 2.4: *Means (and standard errors) of pre-induction and post-induction pitch shift judgment biases and standard errors per question phrasing per mood group of Experiment 2.*

Pitch shift judgment bias	Question phrasing			
	Positively confounded[1] mood induction group		Negatively confounded[1] mood induction group	
	Happy ($N = 13$) M (SE)	Sad ($N = 14$) M (SE)	Happy ($N = 12$) M (SE)	Sad ($N = 15$) M (SE)
Pre-induction pitch shift judgment bias[2]	-0.139 (0.061)	-0.034 (0.059)	0.000 (0.064)	-0.081 (0.057)
Post-induction pitch shift judgment bias[2,3]	0.013 (0.037)	-0.066 (0.035)	-0.038 (0.038)	-0.085 (0.034)

Notes:

1. The question the participants answered to indicate pitch shift judgment was phrased in such a way that the response selection bias could be either a positive or a negative confounding variable.
2. A score of 0 indicates no bias, while a score of 1 indicates full bias towards up judgments and a score of -1 indicates full bias towards down judgments.
3. Adjusted for the pre-induction pitch shift judgment bias.

Discussion

Given that the interaction effect of mood and question phrasing on pitch shift bias was not significant the data of Experiment 2 do not provide support for the concern that effects of mood are driven by response selection bias. However, while the difference in pitch shift bias between the mood groups was in the expected direction, the effect of mood was only marginally significant. Therefore, the findings of Experiment 2 did not provide conclusive evidence regarding the effect of mood on pitch shift judgment. Given that the effect of mood on pitch shift bias in Experiment 1 was rather small, insufficient power may have led to failure to detect an effect in Experiment 2. Therefore, we combined the data of Experiment 1 and 2 and carried out similar analyses as for Experiment 2. Because pitch shift bias and response selection bias were confounded in Experiment 1, we considered question phrasing in Experiment 1 as similar to question 2 in Experiment 2.

Results Experiment 1 and 2 combined

Interaction effects with experiment

Before analyzing the effects of mood and question phrasing we tested if there was an interaction of mood and experiment on pitch shift bias. The pitch shift judgment bias did not differ significantly between the groups at pre-induction, and there was no significant interaction of mood and experiment, $F\text{s}(1,85) < 1$. To test the effect of mood and experiment on the pitch shift judgment bias a two-way analysis of covariance (ANCOVA) was conducted with the pre-induction bias added as covariate to reduce error variance. Pre-induction bias was indeed significantly related to post-induction bias, $F(1,84) = 53.54$, $p < .001$, $\eta_p^2 = 0.39$. The assumption of homogeneity-of-regression-slopes was met ($F\text{s}(1,82) < 1$). The ANCOVA showed that the happy group had a stronger tendency than the sad group to judge the pitch shift of the tone pairs as ascending, $F(1,84) = 8.56$, $p = .004$, $\eta_p^2 = 0.09$, $MSE = 0.021$, 95% CI[0.030, 0.156]. Mood did not show a significant interaction with experiment, $F(1,84) < 1$, which indicated that the mood effect on pitch shift judgment did not depend on the experiment in a statistically significant manner and we continued analyzing the two experiments together.

Control task

The proportion of correctly identified (unambiguous) pitch shifts in the control task did not differ between the sad ($M = 0.89$, $SE = 0.02$) and happy group ($M = 0.92$, $SE = 0.02$), $F(1,85) < 1$, there was no significant effect of question phrasing, $F(1,85) < 1$, and there was no interaction between mood and question phrasing, $F(1,85) < 1$. This indicates that both mood groups had equal pitch shift identification abilities and that this did not depend on question phrasing.

Test of main hypotheses: Pitch shift judgment bias or response selection bias

The pitch shift judgment bias did not differ significantly between the groups at pre-induction, $F(1,85) < 1$, and there was no significant effect of question phrasing, $F(1,85) < 1$, or a significant interaction of mood and question phrasing, $F(1,85) = 1.83$, $p = .179$, $\eta_p^2 = 0.02$, on the pre-induction bias. To test the effect of mood and question phrasing on the pitch shift judgment bias a two-way analysis of covariance (ANCOVA) was conducted with the pre-induction bias added as covariate to reduce error variance. Pre-induction bias was indeed significantly related to post-induction bias, $F(1,84) = 53.01$, $p < .001$, $\eta_p^2 = 0.39$. The assumption of homogeneity-of-regression-slopes was met, $Fs(1,82) < 1$. The ANCOVA showed that the happy group had a stronger tendency than the sad group to judge the pitch shift of the tone pairs as ascending, $F(1,84) = 4.80$, $p = .032$, $\eta_p^2 = 0.05$, $MSE = 0.012$, 95% CI[0.007, 0.142]. There was no significant interaction effect between mood and question phrasing, $F(1,84) < 1$. This indicates that the effect of mood on the pitch shift judgment bias did not significantly depend on the way the question was phrased.[7] Figure 2.1 shows the means and 95% confidence intervals for the adjusted post-induction pitch shift bias per mood group per and type of question phrasing for Experiment 1 and 2 combined.

2.4 General Discussion

The pattern of results of Experiment 1 and 2 combined provides support for the hypothesis that mood has an effect on pitch shift judgement and that this effect is not due to response selection bias. We found a main effect of mood on pitch shift judgment, which did not depend on whether response bias was a possible positive or a negative confounding variable. The main effect reflects that sad listeners judge tone pairs with ambiguous pitch shifts more often as downwards than happy listeners. This effect cannot be attributed to response selection bias because participants indicated pitch shift direction in two different ways. For some participants response bias was a possible positive confounding variable and for others it was a possible negative confounding variable. Therefore, across participants, positive and negative confounding effects of response bias, if present, canceled each other out. The current findings of the effect of mood on pitch shift judgment fit with the affect-as-information account of mood congruent judgments. According to this theory, one's current affective state serves as information for judging objects or events. Because of the ambiguous nature of the pitch shifts in the current task, participants may have used additional affective information in their judgment of the pitch shift. As

[7] When participants who had a pleasure score during the task deviating less than one point in the desired direction from neutral mood were included in the analyses the effects of mood were the following: The ANCOVA showed no significant main effect of mood, $F(1,100) = 1.62$, $p = .206$, $\eta_p^2 = 0.05$, $MSE = 0.03$, 95% CI[-0.024, 0.111], although numerically the happy group had a slightly stronger tendency than the sad group to judge the pitch shift of the tone pairs as ascending. There was no significant effect of question phrasing and no significant interaction effect between mood and question phrasing, $Fs(1,100) < 1$. Conclusions regarding covariate and the assumptions of the ANCOVA were the same as when the participants were excluded.

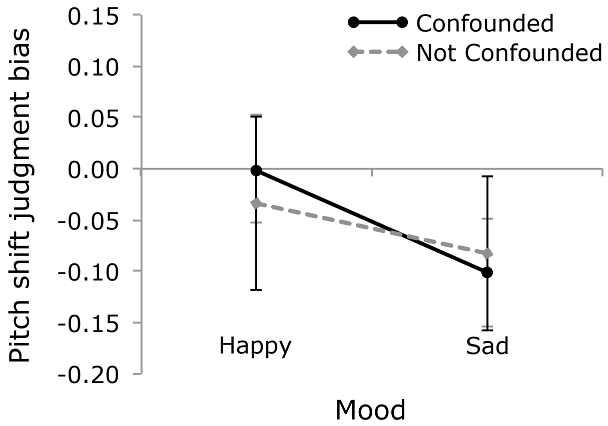

Figure 2.1: Means and 95% confidence intervals of the adjusted pitch shift bias per mood group and type of question phrasing of Experiment 1 and 2 combined.
Notes:

1. The question the participants answered to indicate pitch shift judgment was phrased in such a way that the response selection bias could be either a positive or a negative confounding variable.
2. A score of 0 indicates no bias, while a score of 1 indicates full bias towards up judgments and a score of -1 indicates full bias towards down judgments.
3. Post-induction pitch shift bias is adjusted for the pre-induction pitch shift judgment bias.

sad feelings could result from the descending pitch shifts (Collier & Hubbard, 2001), ambiguous pitch shifts in a sad mood may be more readily experienced as going downwards than upwards.

While the affect-as-information theory provides a plausible explanation, other accounts for the present findings are also worth considering. Studies have shown that selective attention, a relatively early cognitive mechanism, is facilitated for mood congruent information. Attention to rewarding information is facilitated in a positive mood (Tamir & Robinson, 2007), while attention to negative information is facilitated in a negative mood (Becker & Leinenger, 2011). In the ambiguous pitch task, attention mechanisms may have played a role in biasing the competition between the two pitch shift directions (Desimone & Duncan, 1995), enhancing perception of the mood congruent pitch shift.

Finally, Lakoff and Johnson's (1980) Conceptual Metaphor Theory provides another mechanism that may explain our findings (Crawford, 2009). According to this theory, abstract concepts such as affect are represented in a deeper, more embodied, way by means of conceptual metaphors that link these concepts to concrete sensory experience (e.g., affect is linked to vertical position, happy = up, sad = down; Crawford, 2009; Meier & Robinson, 2004). Consequently, whenever an affective feeling is activated this activates conceptual metaphors that bias perception. Several studies provide support for this idea (for a review, see Crawford, 2009). For example, Meier and Robinson (2004) showed that people are faster to detect probes in the lower than higher visual field after making a positive compared to a negative evaluation. Comparable biases have been found in the auditory domain. After judging a negative compared to a positive word, participants are faster and more accurate to categorize a low than a high tone (Weger et al., 2007). Similarly, positive or negative affect elicited by the mood induction procedure in the present study may have activated concepts of ascending or descending pitch respectively, biasing subsequent pitch shift judgments.

While the findings are in line with these theories, several limitations warrant some caution in drawing strong conclusions regarding the effect of mood on pitch shift judgment. First, the current study does not give full insight into the level at which the effects of mood on pitch shift judgment take place. As discussed above these effects may occur at an early attentional level, increasing the sensitivity towards upwards pitch shift in a happy state and to downwards pitch shift in a sad state. However, even though the analysis of Experiment 1 and 2 combined excluded a response selection bias as explanation for the pitch shift bias, the current results may also be driven by a lower decision criterion for judging a pitch shift as upwards in a happy state compared to a sad state. Thus, in terms of signal detection theory, it is not clear whether our results reflect changes in sensitivity or in response criterion. While effects of mood on sensitivity and response criterion both are relevant for perceptual decision making, future research should address this issue, for example by using a signal detection paradigm.

Second, the current study does not allow generalization of the mood effect on pitch shift bias to the general population because our main analyses included only participants that reported strong subjective mood during the task in the desired direction. In fact, there was a significant interaction effect between strength of mood (centered deviation from the midpoint (5) of the pleasure scale) during the task and mood group on pitch shift bias, $F(1,100) = 4.80$, $p = .012$, $\eta_p^2 = 0.06$, $MSE = 0.03$. This was also reflected in the results of the analyses including both participants with weak and strong mood scores (presented in footnotes), which showed that the effects of mood did not reach significance. It is therefore desirable to replicate the current findings using a mood induction procedure that elicits sufficiently strong moods for each participant. A recent meta-analysis of mood-induction procedures (Joseph et al., 2020) showed that, although autobiographic recall is an effective procedure to elicit moods, using images of happy or sad facial expressions is particularly effective to elicit happy or sad moods. Therefore images of happy or sad facial expressions may be recommended for follow-up studies. Furthermore, another reason why generalizability may be limited is that most of the participants in Experiment 1 and all participants in Experiment 2 were female. Generalizability of the current results to male listeners may also be explored in future studies.

Third, the effect of mood on pitch shift bias is rather small and multiple other factors may contribute to this bias. For example, the pitch shift bias seems strongly determined by individual differences given that the pre-induction pitch shift bias explained a substantial amount of variance of the post-induction pitch shift bias (see partial eta squares). This may explain why the effect only becomes apparent when subjectively experienced mood is strong. Future studies may employ different ambiguous pitch shift stimuli, such as pairs of Shepard tones with frequency intervals of half an octave between them (see the Introduction chapter of this thesis), for which idiosyncratic biases may be more easily balanced out and for which strong malleability of pitch shift perception by auditory context has been demonstrated (Chambers et al., 2017). A conceptual replication of the current study using such stimuli would also be of great value to test the robustness of mood biased pitch shift judgment.

Despite its limitations, the findings of this study showed that mood biases pitch shift judgment, at least in females who experience relatively strong mood. This may be a direct perceptual effect, or a result of interactions between affect and cognition at higher levels of processing exerting top-down influence on perceptual judgment. Regardless of the exact underlying mechanism, the current findings warrant further investigation into mood congruency effects in perception, not only in vision but also in audition. Because in the current experiment the effect was limited to participants who reported strong moods, it may be of interest to investigate the effect in groups with more extreme moods, such as in individuals suffering from mood disorders. Furthermore, as mood congruent biases are suggested to play a crucial role in the expression, aetiology and maintenance of mood disorders (Beevers & Carver, 2003; Meier & Robinson, 2006), increased understanding of the pervasiveness of mood at all levels of processing could also have clinical importance. Our findings contribute to this understanding by showing for the first time that not only evaluative judgments but also auditory perceptual judgments are modulated in a mood congruent fashion.

Acknowledgments

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3

Inconsistent Effect of Arousal on Early Auditory Perception

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Mood has been shown to influence cognitive performance. However, little is known about the influence of mood on sensory processing, specifically in the auditory domain. With the current study we sought to investigate how auditory processing of neutral sounds is affected by the mood state of the listener. This was tested in two experiments by measuring masked auditory detection thresholds before and after a standard mood-induction procedure. In the first experiment ($N = 76$) mood was induced by imagining a mood-appropriate event combined with listening to mood inducing music. In the second experiment ($N = 80$) imagining was combined with affective picture viewing to exclude any possibility of confounding the results by acoustic properties of the music. In both experiments the thresholds were determined by means of an adaptive staircase tracking method in a two-interval forced-choice task. Masked detection thresholds were compared between participants in four different moods (calm, happy, sad, anxious), which enabled differentiation of mood effects along the dimensions arousal and pleasure. Results of the two experiments were analyzed both in separate and in a combined analysis. The first experiment showed that, while there was no impact of pleasure level on the masked threshold, lower arousal was associated with lower threshold (higher masked sensitivity). However, as indicated by an interaction effect between experiment and arousal, arousal did have a different effect on the threshold in Experiment 2. Experiment 2 showed a trend of arousal in opposite direction. These results show that the effect of arousal on auditory masked sensitivity may depend on the modality of the mood inducing stimuli. As clear conclusions regarding the genuineness of the arousal effect on the masked threshold cannot be drawn, suggestions for further research that could clarify this issue are provided.

Keywords: mood, arousal, hearing, masked auditory threshold, psychophysics, affective modulation, auditory perception

3.1 Introduction

Affective states, such as moods and emotions are thought to facilitate adaptive responding to situational demands. Several studies have demonstrated that changes in emotional states are associated with changes in perceptual or cognitive processes, including visual perception (Bocanegra & Zeelenberg, 2009; Gasper, 2004; Kuhbandner et al., 2009; T.-H. Lee, Baek, et al., 2014; Phelps et al., 2006), temporal attention (Jefferies, Smilek, Eich, & Enns, 2008), spatial attention (Phelps et al., 2006) and cognitive control (Kuhbandner & Zehetleitner, 2011; van Steenbergen, Band, & Hommel, 2010; van Wouwe, Band, & Ridderinkhof, 2009). Influences of mood on basic auditory processing, however, have remained largely unexplored (for a recent exception, see E. H. Siegel & Stefanucci, 2011). To fill this gap, we investigated the effects of mood state on the masked auditory threshold in two experiments. In the first experiment, mood was induced by imagining a mood-appropriate event while listening to mood inducing music. In the second experiment we used a visual mood induction procedure.

Although there has been little research interest in mood-induced modulation of auditory compared to visual processing, mood-induced modulation in the auditory domain does seem highly plausible. Firstly, it has been argued that the auditory system is particularly suitable to function as alarm system because the auditory system enables detection of potentially relevant stimuli, within as well as outside of our visual field of view (Asutay & Västfjäll, 2015; Juslin & Västfjäll, 2008). Modulation of the auditory system by affective state may enhance detection of these potentially relevant stimuli and thereby increase chances of survival. For example, the need for an organism to invest in high auditory sensitivity may be higher in dangerous conditions, associated with more negative or aroused affective states, than in safe conditions, associated with more positive or relaxed affective states. Secondly, evidence is accumulating that the auditory system is well equipped to adapt to demands of the environment (Fritz et al., 2007; B. L. Robinson & McAlpine, 2009). Animal studies demonstrate that gain control mechanisms are operating at multiple levels in the auditory system (B. L. Robinson & McAlpine, 2009), for example in the inferior colliculus (Dean et al., 2005) in the midbrain and the auditory cortex (Rabinowitz et al., 2011). In addition, neuronal receptive fields can reshape rapidly as a consequence of changes in task demands (Fritz et al., 2007) and descending pathways modulate neuronal responses to signals in noise in the auditory nerve (Kawase, Delgutte, & Liberman, 1993), the cochlear nucleus (Mulders, Seluakumaran, & Robertson, 2008) and the inferior colliculus (Seluakumaran, Mulders, & Robertson, 2008). These forms of plasticity in the auditory system enable enhanced coding of salient or relevant stimuli (Fritz et al., 2007; B. L. Robinson & McAlpine, 2009) and may enable affective modulation. Furthermore, Fritz et al. (2007) conjecture that the rapid adaptations in tuning in the auditory cortex are mediated by neuromodulators such as dopamine (DA), norepinephrine (NE) and serotonin (5HT). Activity changes of these neuromodulators are also implicated in changes in affective state (DA, Ashby et al., 1999; NE, Aston-Jones et al., 1996; 5HT, R. L. C. Mitchell & Phillips, 2007), which may hint at a neural mechanism for affective modulation of the auditory system. Taken together, mood modulation of auditory processing appears plausible on functional as well as on neural grounds.

While studies of mood effects on audition are rare, several effects of brief affective states on auditory processing have been reported. For example, the wave V of the brain stem auditory evoked potentials (BAEPs), an early reflection of inferior colliculus activity in the brainstem, was modulated by fear of mild electric shock (Baas, Milstein, Donlevy, & Grillon, 2006). This suggests that heightened activation of structures involved in defensive states, such as the amygdala and locus coeruleus (LC), modulate auditory processing in the brainstem. In addition, using a similar threat-of-shock-paradigm, Al-Abduljawad, Baqui, Langley, Bradshaw, and Szabadi (2008) showed that also a later component of the auditory evoked potential, the N1/P2, was potentiated in threatening conditions.

In contrast to the above mentioned studies that involved brief affect inductions, in the current study we investigated modulation of auditory processing by mood, which is a more diffuse affective state longer in duration (E. Gray & Watson, 2007). In addition, following previous studies that demonstrated effects of emotion cues on contrast sensitivity in the visual domain (Bocanegra & Zeelenberg, 2009; T.-H. Lee, Baek, et al., 2014; Phelps et al., 2006), we used a perceptual performance measure rather than brain indices of auditory processing. To the best of our knowledge only one other recent study has investigated how mood impacts basic auditory perception (E. H. Siegel & Stefanucci, 2011). In this study a negative mood was induced by means of an autobiographical memory writing task after which participants were asked to rate duration and loudness of short neutral tones on an anchored scale. Sounds were judged as louder by participants in an anxious mood compared to participants in a neutral mood. No differences were found in duration perception between the two groups. These findings provide further evidence for affective modulation of auditory processing but also raise several questions that we aim to answer in the current study.

A first question that arises is whether the mood effects on loudness judgment observed by E. H. Siegel and Stefanucci (2011) might actually reflect response bias, rather than modulation of perceptual sensitivity (Marks & Florentine, 2011; Odgaard, Arieh, & Marks, 2003). Response bias is determined by the (implicit) criterion, or rule, an observer employs in translating sensory information into overt responses. Measures of magnitude on a subjective scale are assumed to be prone to effects of response bias (Dalton, 1996; Odgaard et al., 2003). In order to rule out that alternative explanation, in the present study we used a performance measure of auditory perception that minimizes such biases. A two-interval forced choice (2IFC) procedure was combined with a staircase procedure (García-Pérez, 1998) to measure the masked auditory detection threshold for pure tones, which reflects listeners' ability to detect faint sounds in noise. In terms of signal detection theory the 2IFC procedure is often regarded as a criterion-free measure, that is, it measures sensitivity irrespective of the response criterion used by the observer (Gillmeister & Eimer, 2007; Green & Swets, 1966; Kingdom & Prins, 2010; Odgaard et al., 2003).

We chose to measure the masked auditory threshold (in noise) rather that the absolute threshold of hearing (in quiet) for two reasons. First, in real-life listening, our ability to detect faint sounds is almost always limited by the ambient noise that masks those sounds, not by our absolute sensitivity to those sounds (see Moore, 2012). Second, the adaptive 2IFC procedure measuring the masked auditory threshold was shown to have better reliability (lower intrasubject standard deviation) than the same procedure measuring the absolute threshold (Marshall et al., 1996). To emphasize that the masked auditory threshold not only depends on sensitivity to the to be detected faint tones but also on the effects of the masking noise, we will refer to the inverse of the masked threshold as masked sensitivity.

The masked auditory threshold task in the current study involved detecting a 1 kHz tone signal in a constant white noise as masker. These masking conditions are often labeled as simultaneous masking and energetic masking conditions (Moore, 2012). Simultaneous masking refers to the situation where the tone and mask are presented simultaneously. Energetic masking refers to the situation where masking results from overlap in the excitation patterns to the signal and the noise at the level of the auditory periphery (Moore, 2012; Oxenham et al., 2003). Simultaneous energetic masking can be largely explained by frequency tuning of the basilar membrane in the cochlea (Moore, 2012; Recio-Spinoso & Cooper, 2013). This does not, however, exclude the possibility of (top-down) modulation that may affect the masked auditory threshold. Even cochlear responses are thought to be susceptible to modulation through efferent pathways from higher centers of brain to the outer hair cells (D. W. Smith et al., 2012). This may explain effects of cueing and expectancy on masked sensitivity that have been found (Tan, Robertson, & Hammond, 2008). Furthermore, as described above, higher auditory centers can further modulate the signal coming from the cochlea by gain control mechanisms and through rapid reshaping of neuronal receptive fields.

A second question that arises from the findings of E. H. Siegel and Stefanucci (2011) concerns which aspect of the affective state contributed to the modulation. According to emotion theorists affective states can be described by two main dimensions, pleasure (or valence) and arousal (or activation; J. A. Russell, 2003; Yik et al., 1999). Pleasure reflects the hedonic value of the affective state, ranging from unpleasant to pleasant, and arousal reflects the sensation of activation or energy mobilization, ranging from sleepy to activated (J. A. Russell, 2003). Previous studies have demonstrated specific pleasure or arousal effects depending on the type of cognitive abilities measured (Jefferies et al., 2008; Kuhbandner & Zehetleitner, 2011; van Steenbergen et al., 2010). Furthermore, different neuromodulatory systems may mediate different affective states. Hedonic value is often associated with DA (Ashby et al., 1999), while arousal is associated with NE (Aston-Jones et al., 1996). Neuro-computational models relate both DA and NE activity to gain modulation at the neuronal level, which at the functional level changes the ability to detect a signal from a noise background (Servan-Schreiber, Printz, & Cohen, 1990). As described above, both neuromodulators may play a role in situational adaptation of the auditory system.

E. H. Siegel and Stefanucci (2011) compared loudness perception only between participants in an anxious and a neutral state. An anxious state is both lower in pleasure level and higher in arousal level than a neutral state. It thus remains to be answered whether affective modulation of loudness depends on pleasure or arousal, or a combination of both. To disentangle the effects of pleasure and arousal on auditory perception, in the present study we used a standard mood induction procedure to elicit four different moods that can be differentiated along the dimensions arousal and pleasure (Jefferies et al., 2008; Kuhbandner & Zehetleitner, 2011; van Steenbergen et al., 2010). Moods were induced in four different groups of participants: anxious (low pleasure, high arousal), sad (low pleasure, low arousal), happy (high pleasure, high arousal) and calm (high pleasure, low arousal). Comparison of auditory perception between these groups allowed assessing the separate contribution of pleasure and arousal.

Theoretical accounts of effects of the pleasure dimension of mood on perception and cognition (e.g., Derryberry & Tucker, 1994; Fredrickson, 2004) have not explicitly dealt with basic auditory information processing. Therefore predictions for the present study based on these theories can only be formulated indirectly. With respect to basic visual perception a widely accepted claim is that positive mood broadens the perceptual scope, while negative mood narrows it (Derryberry & Tucker, 1994; Fredrickson & Branigan, 2005; Gasper & Clore, 2002). Experiments using a visual global-local task have confirmed that people in a positive mood attend more to global features of a figure and less to the smaller details than people in a negative mood (Fredrickson & Branigan, 2005; Gasper & Clore, 2002). Furthermore, stronger interference of irrelevant stimuli flanking a target stimulus in positive than in negative mood also suggests that the scope of spatial attention is broadened in positive mood (Rowe, Hirsh, & Anderson, 2007). There is no one-to-one correspondence between global-local visual processing tasks, tasks measuring spatial breadth of visual attention and the masked auditory threshold task. However, it has been suggested that frequency in the auditory domain may play a similar role in attentional selectivity as spatial location does in the visual domain (Woods, Alain, Diaz, Rhodes, & Ogawa, 2001). Therefore, increased breadth of attentional scope in the visual domain may be reflected in decreased frequency selectivity in the auditory domain, thereby increasing the threshold for a specific frequency in a noise background. If positive mood broadens frequency tuning, while negative mood leads to more narrow tuning, thresholds are expected to be lower in negative than in positive moods.

The above mentioned theories on mood and perceptual scope do not accommodate effects of affective arousal regardless of pleasure on perception and cognition. A classic observation is the inverted U-shaped relation between arousal and performance on various (perceptual and perceptual-motor) tasks (K. J. Anderson, 1990; Aston-Jones & Cohen, 2005; Easterbrook, 1959; Kahneman, 1973; Yerkes & Dodson, 1908). If arousal similarly influences auditory perceptual performance, it is expected that there is an optimal level of arousal at which masked auditory thresholds will be lowest; at levels below and above this optimum, thresholds will be higher.

3.2 Experiment 1: Masked Auditory Threshold in Moods Induced by Music and Imagining

Method

Participants

Eighty-one participants (Age: $M = 20.5$, $SD = 2.0$, $18-27$ years; 20 males) with no self-reported hearing problems or depression took part either for course credit or payment (€ 5). They were randomly assigned to one of four mood groups: calm, happy, sad, and anxious. Data from five participants were not included in the analyses because they had strongly deviating baseline or test thresholds according to the three interquartile range criterion (3IQR criterion; see section 2.2) for their assigned mood group. All participants gave written informed consent before the start of the study. The study was approved by the ethics committee of the Institute of Psychology of Leiden University.

Apparatus

Stimulus presentation was controlled by E-prime 2 software (W. Schneider et al., 2002) using a computer with a CRT screen (75 Hz refresh rate, 1024 x 768 resolution). Responses were made on a QWERTY keyboard and by using a mouse. Sound was binaurally presented through insert earphones (Etymotic ER-4B microPro) with 3-flange eartips that provide 35 dB external noise attenuation.

Sound levels

Sound levels at output were calculated from the voltages delivered at the earphone input as measured with an oscilloscope (Type Tektronix TDS2002) and the earphone efficiency as provided by the earphone manufacturer (108 dB SPL for 1 Vrms in a Zwislocki coupler, ER-4 datasheet, Etymotic Research, 1992).

Mood induction and assessment

Mood was induced by listening to music and imagining a mood-appropriate event. This standard procedure has been shown to elicit reliable changes in mood (Eich et al., 2007) and has been successfully used in previous studies (Jefferies et al., 2008; Kuhbandner & Zehetleitner, 2011; van Steenbergen et al., 2010). Following these examples we manipulated mood according to two factors (pleasure and arousal). No neutral control condition was included. The power of such a design is larger than when all mood conditions need to be compared to a neutral condition. Furthermore, it is rather difficult to establish a neutral mood condition. This becomes apparent from the results of Jefferies et al. (2008), who initially included a neutral (no induction procedure) condition but assigned these participants later to different mood groups on the basis of their subjective arousal and pleasure ratings.

Participants were instructed to get into the desired mood by vividly imagining and writing down in detail a mood-appropriate event, either based on their own past experience or on a given scenario. Simultaneously they listened to a selection of classical music excerpts which were validated to promote a particular mood (Jefferies et al., 2008). An overview of the scenarios and musical pieces used per mood condition can be found in Table 3.1.

Per condition two excerpts were combined to one mp3 file with a minimum duration of 11 minutes to cover the duration of the mood induction procedure. The Root Mean Square (RMS) value of each excerpt was first normalized to the average RMS value of the excerpts using RMS based normalization with equal loudness contours in Cool Edit pro software. Further, the combined files were normalized across conditions to the same level also using RMS based normalization with the equal loudness contour in Cool Edit pro. Equivalent continuous sound level (L_{eq}) for each music file was estimated using the following procedure: RMS values per 4.5 ms time-window of the first 10 min and 20 s (the average duration of the mood induction procedure) of each music file were computed. Next, voltages at earphone input were estimated for each window from the ratio of the RMS amplitude and the measured voltage at earphone input for a 1 kHz tone. Subsequently, L_{eq} at output was computed from the estimated voltages at earphone input and earphone efficiency. The estimated level, for all files, was approximately $L_{eq} = 49.5$ (± 1) dB. Note that

Table 3.1: *Music and example scenarios per mood condition as used in the mood induction procedure of Experiment 1.*

Mood condition	Name (and composer) of musical piece	Duration of musical piece (min:sec)[1]	Example scenario (text translated from Dutch and slightly shortened)
Anxious (Low pleasure, High arousal)	Mars, The Bringer of War (Holst) Uranus the Magician (Holst)	07:12 06:05	Together with a good friend you are taking a roller coaster ride in an amusement park. At the moment you drive off you realize that the safety lever is lose. You are in danger of falling out!
Sad (Low pleasure Low arousal)	Piano Quintet No. 1 in D Minor (Fauré) Violin Concerto: Adagio di Molto (Sibelius)	08:11 08:06	You are visiting a good friend who is ill in bed. You are told the bad news that your friend is very seriously ill and does not have much longer to live. This will likely be the last time that you will see your friend.
Happy (High pleasure, High arousal)	Eine Kleine Nachtmusik: Allegro (Mozart) The Nutcracker: Waltz of the Flowers (Tchaikovsky)	06:31 06:23	You are in a shop together with a friend. On a whim, you decide to buy a scratch card. After scratching the card you find out that you've won the jackpot of 50.000 euro!
Calm (High pleasure, Low arousal)	Venus, The Bringer of Peace (Holst) Ave Maria (Bach)	09:33 04:23	You arrive home after a long day at work. You take a well-deserved warm bath to let your tired body rest. The foam and warmth of the water make you dream away about faraway places.

Note 1: Music stopped playing when the mood induction procedure was finished.

this was kept well below L_{eq} = 70 dBA to avoid effects of music exposure on the masked auditory threshold. Previous research has shown that after 10 minutes of loud noise (e.g., 105 dB SPL), a temporary shift in auditory thresholds occurs, while after exposure to low level music (L_{eq} = 70 dBA) the auditory threshold is not altered (Miyakita, Hellström, Frimanson, & Axelsson, 1992).

Over the course of the experiment participants rated their current mood six times on an electronic version of the 9x9 affect grid (J. A. Russell et al., 1989). Pleasure was indicated on the horizontal axis (extremely unpleasant [1] to extremely pleasant [9]) and arousal on the vertical axis (extremely low arousal [1] to extremely high arousal [9]). These ratings were used to check if the induction procedure had succeeded.

Threshold task

Sounds

For all sounds used in the threshold task, digital sound properties were standardized (44 kHz, 16 bit, mono, binaural). The signal was a 500 ms, 1 kHz pure tone with 10 ms ramped on- and offset, presented at a sound level of 68 dB SPL as initial value for the adaptive procedure. An empty sound file of 500 ms served as non-signal. Both files were created with Audacity software. The masking noise that was constantly present during the threshold tasks was white noise (20 Hz - 10 kHz band-filtered) generated in Goldwave software. The white noise was presented with a voltage delivered at the earphone input that would equal 38 dB SPL output for 1 kHz tone (108 dB SPL/1Vrms).

Task procedure

Masked auditory thresholds were determined twice (pre- and post- mood induction) by means of an adaptive two interval forced choice (2IFC) task. Figure 3.1A shows the trial structure of this task. Each trial started with a fixation cross presented in the center of the screen for 1000 ms. This was followed by two observation-intervals each of 700 ms indicated with a number presented in the center of the screen (1 or 2) and separated by an inter-observation interval of 700 ms. On each trial one of the two observation intervals was randomly selected to contain the signal with the constraint that maximally four trials with the same selected interval could occur in succession. The 500 ms signal was centered in the observation interval. The second observation interval was followed by a 100 ms blank screen after which a red “X” appeared in the center of the screen that prompted the participants to indicate whether they had heard the signal in the first or the second interval by pressing the z-key on the keyboard with their left index finger or the m-key on the keyboard with their right index finger respectively. The sound level of the signals was increased or decreased adaptively to the performance of the participant according to a transformed and weighted up/down rule (García-Pérez, 1998). This adaptive way of measuring is more efficient (fast while accurate) than other classic psychophysical methods used to determine the threshold (e.g., method of constants or method of limits), because most observations are obtained around the level of interest (e.g., the 80% detection level) on the psychometric curve (Kingdom & Prins, 2010; Leek, 2001; Levitt, 1971). Efficiency is very important when investigating effects of mood, because induced moods last for a relatively short time period, up to 20 minutes depending on the type of induction and the tasks performed (Frost & Green, 1982; Isen et al., 1976; Isen & Gorgoglione, 1983). The task duration fell within this period: The average duration of the threshold task after the mood-induction procedure was $M = 3$ min and 35 s ($SD = 29$ s) for Experiment 1. We used a combination of the 1up/2down rule and a ratio of the stepsize down and stepsize up of 0.548 which has been shown to reliably converge to 80.35% correct performance (García-Pérez, 1998). Thus, the sound level of the tone went up one step (e.g., 3 dB) after one incorrect trial but went down one step only after two consecutive correct trials, with the stepsize up being 1.82 times the size of the step down. The initial stepsize down was 15 dB, which changed to 5 dB after two reversal points (trials at which the sound level changed from going up to down or vice versa) and to 3 dB after four more reversal points. The sound levels of tones at the last 10 reversal points were averaged to calculate the threshold, or sound level needed for 80% performance. The E-prime script for the adaptive procedure was adapted from Hairston and Maldjian (2009).

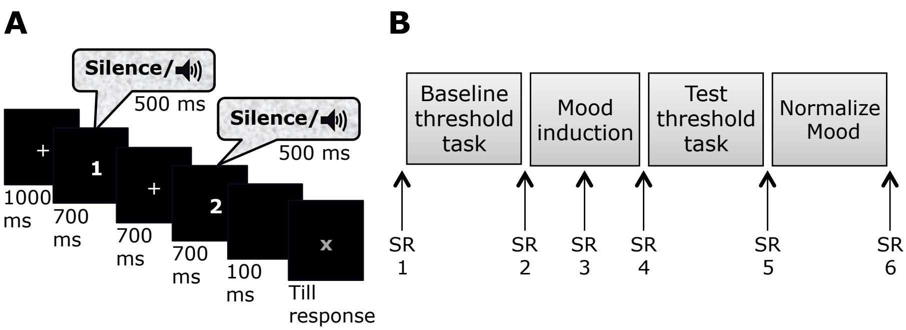

Figure 3.1: (A) Trial set-up of the threshold task. (B) Experimental timeline for Experiment 1 and 2, SR = subjective rating of pleasure and arousal on the affect grid.

Experiment Procedure

After reading and signing an informed consent, participants were guided to a quiet dimly lit individual test cubicle. They were instructed about the flow of the experiment and how to rate their mood on the affect grid. They practiced with correct earphone insertion and the experimenter verified whether external sounds were indeed attenuated. They were seated in a comfortable chair at 50 cm from the computer monitor, where further instructions were provided. After filling out the first affect grid the participants were instructed about the threshold task. It was explained that the signal would be presented equally often in each interval, and that an answer was required on all trials even though the signal might be difficult to hear on some trials. Participants were also encouraged to keep paying attention to the task in these cases. Instructions stressed accuracy and all responses were self-paced. In order to get used to the task participants carried out eight practice trials that were equal to the trials of the threshold task except that the sound level of the signals was kept at 68 dB SPL and that participants received feedback about their accuracy after each trial. Following the practice trials and the baseline threshold task the second mood rating was obtained. Subsequently the mood induction procedure started. Participants were asked to write as many details as possible of a mood-appropriate event on a piece of paper provided. To encourage vivid imagination, participants who chose to write about the given scenario were asked to answer six questions specifying the situation (e.g., What is the name of your friend? How does he/she look? What are your first thoughts at that moment? What do you tell your friend? What will be the consequences?). It was emphasized that after the procedure participants could put their notes in an envelope and that their notes would be treated confidentially. Five minutes after the start of the mood induction procedure the third affect grid appeared on the screen indicated by a soft warning tone. When this grid was filled out the mood-induction procedure continued for another 5 minutes. At the end of the procedure the fourth affect grid was completed after which the participants proceeded to the test threshold task. Upon completion of the fifth affect grid, participants were instructed to go back to baseline mood levels. Participants who went through the sad or the anxious mood induction procedure were given candy to alleviate their mood more easily. Subsequently they filled out some additional questionnaires, including two more affect grids, which are not presented in this paper, except for a question concerning whether the thoughts used in the mood induction procedure were based on real or fictional events (two answer options). The final affect grid (referred to as sixth) was taken before participants were thanked, debriefed and paid. Figure 3.1B shows an overview of the experimental procedure.

Results

All reported analyses were analyses of variance (ANOVA) or t-tests unless indicated otherwise. For all analyses a significance level of $\alpha = .05$ was used.

Mood induction manipulation check

Figure 3.2 shows the ratings of arousal and pleasure per moment of measurement during the experiment. Participants started out with a fairly neutral mood as reflected in the experienced level of arousal ($M = 5.36$, $SE = 0.17$) and pleasure ($M = 5.65$, $SE = 0.13$) at baseline (Subjective rating [SR] 1). There were no differences in subjective arousal or pleasure at baseline between the groups assigned to the moods, ps$> .05$.

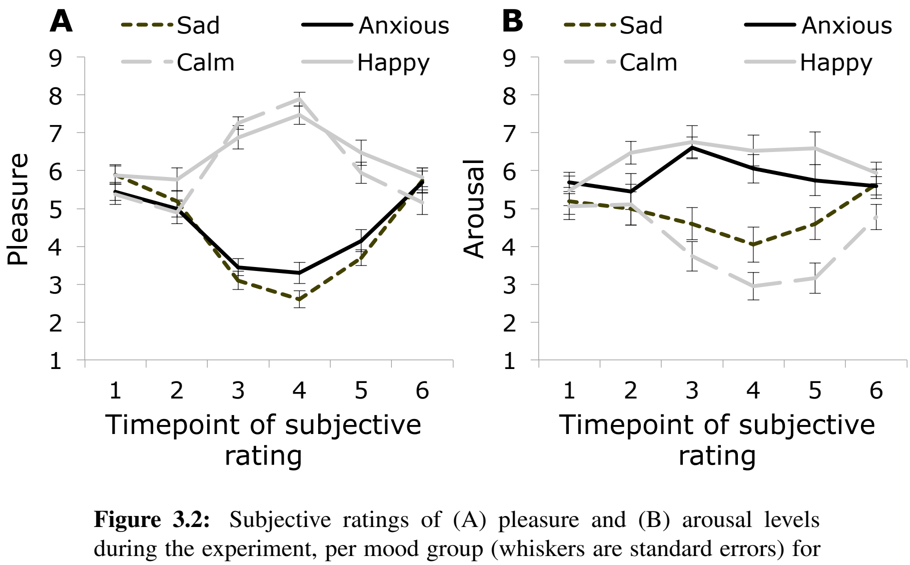

Figure 3.2: Subjective ratings of (A) pleasure and (B) arousal levels during the experiment, per mood group (whiskers are standard errors) for Experiment 1.

Seventy-one percent of the participants indicated they had used events that really happened for the writing and imagining task carried out during the mood induction procedure, and 29% indicated that they used fictional events. Subjective arousal and pleasure level averaged over ratings obtained before and after the threshold task (SR4 and SR5) indicate the experienced mood during task performance. The happy (M = 6.97, SE = 0.24) and calm (M = 6.92, SE = 0.23) groups experienced more pleasure than the anxious (M = 3.73, SE = 0.23), and sad groups (M = 3.15, SE = 0.22), $F(1,72) = 240.67$, $p < .001$, $\eta_p^2 = 0.77$, $MSE = 1.00$. Arousal ratings were higher for the high than the low arousal groups, $F(1,72) = 46.81$, $p < .001$, $\eta_p^2 = 0.39$, $MSE = 2.61$. However, differences in arousal ratings between the happy and calm group were larger than between the anxious and sad group, as indicated by a significant interaction between pleasure and arousal, $F(1,72) = 6.76$, $p = .011$, $\eta_p^2 = 0.09$. Still, the anxious group (M = 5.90, SE = 0.36) experienced more arousal than the sad group (M = 4.33, SE = 0.36), $F(1,38) = 8.61$, $p = .006$, $\eta_p^2 = 0.19$, $MSE = 2.88$. Similarly, the happy group (M = 6.56, SE = 0.32) experienced more arousal than participants in the calm group (M = 3.05, SE = 0.37), $F(1,38) = 47.84$, $p < .001$, $\eta_p^2 = 0.59$, $MSE = 2.32$.

Mood and masked threshold

Table 3.2 shows the means and standard errors of the baseline and test thresholds for the different mood groups in dB SPL (for calculation of sound levels see method section).

Table 3.2: *Baseline and test threshold (dB SPL) per mood group of Experiment 1.*

Threshold	Mood group			
	Low pleasure		High pleasure	
	Low arousal (Sad) (N = 20)	High arousal (Anxious) (N = 20)	Low arousal (Calm) (N = 19)	High arousal (Happy) (N = 17)
	$M(SE)$	$M(SE)$	$M(SE)$	$M(SE)$
Baseline threshold	20.66(0.37)	21.71(0.48)	21.39(0.42)	20.53(0.44)
Test threshold	20.99(0.41)	21.56(0.41)	20.50(0.35)	22.02(0.23)

The baseline threshold did not differ between pleasure groups or between arousal groups, Fs < 1, but there was an interaction between pleasure and arousal $F(1,72) = 4.90$, $p = .030$, $\eta_p^2 = 0.064$, $MSE = 3.53$. However, independent t-test comparisons showed no significant differences between any of the four groups, all ps > .05. To reduce error variance, the baseline threshold was added as a covariate $F(1,71) = 3.57$, $p = .063$, $\eta_p^2 = 0.048$, $MSE = 2.69$, in the analyses of the test threshold. The assumption of homogeneity-of-regression-slopes was met, as indicated by the absence of an interaction between baseline threshold, arousal, and pleasure, $F(3,68) = 1.70$, $p = .176$ $\eta_p^2 = 0.071$, $MSE = 2.61$. Analysis of covariance (ANCOVA) showed that the threshold adjusted for the baseline threshold was higher in the high arousal groups (adjusted $M = 21.78$, $SE = 0.27$) than in the low arousal groups (adjusted $M = 20.76$ $SE = 0.26$), $F(1,71) = 7.93$, $p = .008$, $\eta_p^2 = 0.094$, $MSE = 2.69$. There was no effect of pleasure, $F < 1$, and the interaction effect between pleasure and arousal did not reach significance, $F(1,71) = 2.89$, $p = .093$, $\eta_p^2 = 0.039$. The trend towards an interaction effect was due to a stronger effect of arousal in the high pleasure moods $F(1,33) = 12.11$, $p = .001$, $\eta_p^2 = 0.27$, $MSE = 1.71$, compared to the effect of arousal in the low pleasure moods, $F < 1$, while the direction of these effects was the same in both the low and high pleasure moods.

Given the main effect of arousal and because the relation between arousal and task performance is often described by the classic inverted U-shaped Yerkes-Dodson curve (Aston-Jones & Cohen, 2005; Easterbrook, 1959; Kahneman, 1973), we performed a second-order polynomial sequential regression analysis of the masked auditory threshold on subjective arousal during task performance centered to the mean, after first regressing out the baseline threshold. Because lower threshold indicates better task performance, we expected an upward U-shaped relation between subjective arousal and threshold.

In line with the main effect of arousal found in the ANCOVA, adding centered subjective arousal to the regression model did improve prediction of the test threshold, $R^2_{Change} = .07$, $F_{Change}(1,73) = 5.84$, $p = .018$, compared to the model with the baseline threshold only, $R^2 = .03$, $F(1,74) = 2.40$, $p = .126$. Importantly, adding squared centered subjective arousal to the model with baseline threshold and centered subjective arousal further improved prediction of test threshold, $R^2_{Change} = .05$, $F_{Change}(1,72) < 1$, $p = .045$, which suggests the presence of a U-shaped relation between arousal and threshold in addition to the linear relationship. Table 3.3 shows the beta values with standard errors and standardized betas per predictor. For the purpose of visualization, Figure 3.3 shows a scatter plot of individual threshold scores adjusted for the baseline threshold scores as a function of centered subjective arousal scores and the quadratic polynomial regression line.

Table 3.3: *Unstandardized regression coefficients (B), standardized regression coefficients (β), and p-values for the regression of test threshold on: baseline threshold (Step 1); baseline threshold and centered subjective arousal (Step 2); baseline threshold, centered subjective arousal, and squared centered subjective arousal (Step 3) of Experiment 1.*

	$B(SE)$	β	p
Step 1			
Intercept	17.86(2.20)		<.001
Baseline threshold	0.16(0.10)	0.18	.126
Step 2			<.001
Intercept	17.74(2.13)		
Baseline threshold	0.17(0.10)	0.18	.103
Linear centered arousal	0.22(0.09)	0.27	.018
Step 3			
Intercept	17.13(2.10)		<.001
Baseline threshold	0.18(0.10)	0.20	.076
Linear centered arousal	0.20(0.09)	0.24	.030
Quadratic centered arousal	0.09(0.04)	0.22	.045

Discussion

The results of Experiment 1 suggest that affective arousal modulates basic auditory processing as measured by the masked auditory detection threshold. The masked auditory threshold was lower for people in a low arousal mood (calm or sad), than for people in a high arousal mood (happy or anxious). This suggests that affective arousal decreases masked sensitivity to pure tones. No effects of the pleasure level of the mood state were found.

These results may seem surprising given earlier demonstrations of augmented auditory evoked responses in brief highly aroused affective states (Al-Abduljawad et al., 2008; Baas et al., 2006) and of increased loudness perception in negative high arousal mood states (E. H. Siegel & Stefanucci, 2011). However, our findings may fit with cognitive and neuro-computational theories of performance and arousal. In his seminal work on affective arousal and performance Easterbrook (1959) suggested that arousal narrows attention to task-relevant information. Up to a certain point this is beneficial for performance, but when relevant information falls outside the narrowing attentional focus, performance deteriorates (Easterbrook, 1959). This idea was

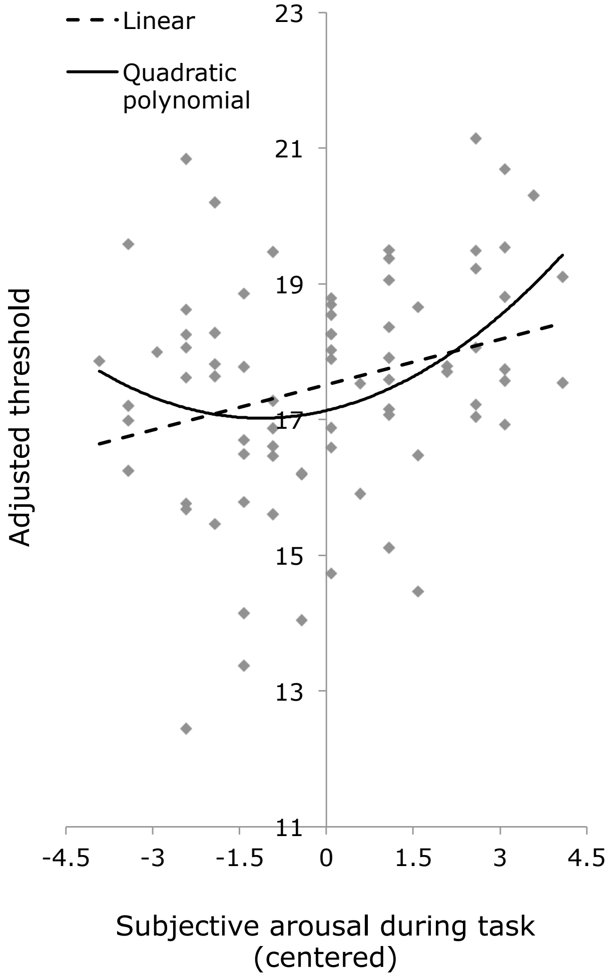

Figure 3.3: Scatter plot of adjusted threshold versus centered subjective arousal for Experiment 1. To be able to visualize the threshold as a function of arousal while controlling for baseline threshold, threshold scores were adjusted as follows: The threshold scores were fitted to a regression model $Y' = B_0 + B_1X_1 + B_2X_2 + B_3X_2^2$, where Y' is predicted test threshold, X_1 is baseline threshold, and X_2 is centered subjective arousal (regression coefficients (B) are presented in Step 3 in Table 3.3). Next, the threshold scores (Y) were adjusted so that $Y_{adjusted} = Y - B_1X_1$. The solid curve shows the quadratic polynomial regression line of adjusted threshold on centered arousal scores, thus representing $Y'_{adjusted} = B_0 + B_2X_2 + B_3X_2^2$.

complemented by Kahneman (1973) who proposed that in addition to a more narrow attentional focus, this focus is allocated in a more labile manner in high arousal states. This also results in impaired performance at high arousal levels due to increased distractibility. More recently, Aston-Jones and Cohen (2005) have proposed a neuro-computational mechanism for the relation between arousal and performance that links increasing arousal, including affective arousal (Aston-Jones et al., 1996), to the increase in tonic (baseline) NE release from the LC.

The LC is a nucleus in the brain stem and the brain's main site of NE production. It modulates many brain areas through its extensive projections. Analogous to the inverted U-shaped relation between arousal and task performance (Easterbrook, 1959; Kahneman, 1973), animal research has shown that the level of tonic activity of the LC also relates to performance on target detection tasks according to an inverted U function (Aston-Jones & Cohen, 2005; Aston-Jones, Rajkowski, & Cohen, 1999; Usher, Cohen, Servan-Schreiber, Rajkowski, & Aston-Jones, 1999). With low levels of baseline (tonic) LC activity, behavior is characterized by inattentiveness and non-alertness. Increases in tonic LC level are associated with an improvement in performance. In this mode of intermediate baseline LC activity, also referred to as "phasic" mode, target stimuli, but not distractor stimuli, elicit strong phasic bursts of LC firing. This results in high levels of NE release in LC projection areas, where NE increases gain of target neurons (Berridge & Waterhouse, 2003), thereby increasing the signal to noise ratio (Servan-Schreiber et al., 1990). These phasic responses are associated with an increase in behavioral responsiveness to targets and thus an improvement in performance (Aston-Jones & Cohen, 2005; Aston-Jones et al., 1999; Clayton, Rajkowski, Cohen, & Aston-Jones, 2004). When tonic LC activity further increases to high levels this is referred to as "tonic mode". In this mode there is hardly any discriminative phasic responding to target stimuli anymore, which is accompanied by a drop in target detection performance and behavior that is characterized by distractibility, labile attention focus and scanning of the environment (Aston-Jones & Cohen, 2005; Usher et al., 1999). These findings from animal research are in line with recent observations in humans of increased distractibility by task-irrelevant stimuli on a visual pop-out distractor task in high arousal moods (Kuhbandner & Zehetleitner, 2011). It is also in line with the older ideas of Kahneman (1973) on increased distractibility in high arousal states.

LC baseline activity also directly influences responsiveness of sensory neurons. This has been demonstrated in a study in which tonic LC firing in rats was directly manipulated through electrical stimulation. Sensory evoked responses of ensembles of somatosensory thalamus neurons were modulated by LC activity according to an inverted U-shape function (Devilbiss & Waterhouse, 2004). A more recent study also investigated changes in responsiveness of neurons in the auditory thalamus and auditory cortex to tones with concomitant phasic LC stimulation. This study showed that about half of the measured evoked responses in the thalamus and auditory cortex increased when accompanied by phasic LC stimulation compared to tone-only trials. This suggests that LC firing also modulates auditory responsiveness (Edeline, Manunta, & Hennevin, 2011).

Taken together, high arousal affective states may be mediated by elevated tonic LC firing (Aston-Jones et al., 1996) and LC tonic firing mode decreases sensory (Devilbiss & Waterhouse, 2004) and behavioral responsiveness to targets (Aston-Jones & Cohen, 2005; Aston-Jones et al., 1999), which results in lower performance. This is in agreement with cognitive theories of arousal and performance (Kahneman, 1973). Our finding of increased masked auditory threshold, indicating decreased ability for detecting target tones in high arousal compared to lower arousal states, may thus be explained by differences in tonic LC firing mode between these states. This idea is further supported by the curvilinear relationship we found between threshold and subjective arousal. Listeners who reported very low subjective arousal or very high subjective arousal had higher thresholds (lower performance) than listeners with a more intermediate level (higher performance).

Our results also seem to be in line with another recent account of the effects of arousal on perception, the arousal biased competition (ABC) theory. According to this theory, arousal enhances the competition between stimuli competing for representation (T.-H. Lee, Itti, & Mather, 2012; T.-H. Lee, Sakaki, Cheng, Velasco, & Mather, 2014; Mather & Sutherland, 2011). This results in heightened processing of salient stimuli at the cost of processing of non-salient stimuli. Furthermore, stimuli with similar salience that compete for representation mutually suppress each other's activation. Because arousal enhances the competition, it decreases activation of the representations even further (T.-H. Lee et al., 2012; T.-H. Lee, Sakaki, et al., 2014). In the present study, the target stimuli (1000 Hz tones) were presented at threshold level and thus had similar salience to the competing background stimulus (masking noise), and activation of the representations for both stimuli would thus be suppressed. Following ABC theory, arousal further suppresses activity of the representations, resulting in the need for higher salience of the target tone to be detected, and thus in a higher detection threshold.

As discussed above, the results of Experiment 1 suggest that irrespective of pleasure level, affective arousal impacted auditory masked sensitivity as measured by the masked auditory threshold and this effect fits with findings of performance changes associated with changes in arousal and tonic NE levels and with the ABC theory. However limitations to Experiment 1 warrant caution in drawing a firm conclusion about the effect of mood on auditory masked sensitivity as measured by the masked auditory threshold.

Although we took care to control for sound level of the musical pieces used for the mood induction, it was not possible to control for all other acoustic properties of the music, such as tempo, mode (minor, major) and other spectral properties. It is those properties that contribute to the differences in pleasure and arousal evoked by the different music pieces (P. Hunter, Schellenberg, & Schimmack, 2010). Because our dependent measure concerned performance on an auditory task, differences in acoustic properties may have directly influenced performance on this task and thus may have confounded the experiment. Indeed, effects have been found of the frequency of a physical or imagined tone (cue) presented before each detection trial and of expectancy of the target tone frequency during the whole task on masked sensitivity (Borra, Versnel, Kemner, van Opstal, & van Ee, 2013; Tan et al., 2008). It should be noted, however, that these studies did not investigate effects of prior exposure to musical pieces on masked sensitivity.

To control for possible confounding by acoustic properties of the music, in Experiment 2 we carried out a study using an identical design to that of Experiment 1 with the exception that we used pictures to complement the mood induction procedure instead of music. If the finding of Experiment 1 that individuals in low (up to an optimal point) arousal mood had lower threshold than individuals in a high arousal mood was a true effect of arousal, we expect similar findings for Experiment 2.

3.3 Experiment 2: Masked Auditory Threshold in Moods Induced by Pictures and Imagining

Method

Participants

Power analysis in G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) indicated a desirable sample size of 78, using a power of .80, an effect size of $f = 0.32$ (equivalent to $\eta_p^2 = 0.094$, the arousal effect size in Experiment 1), an ANCOVA identical to Experiment 1, and alpha at .05. We recruited eighty-four female participants (Age: $M = 19.5$, $SD = 1.7$, $17-24$ years) with no self-reported hearing problems or depression to take part either for course credit or payment (€ 6.50). They were randomly assigned to one of four mood groups: calm, happy, sad, and anxious. Data from three participants were not included in the analyses because they had strongly deviating baseline or test thresholds according to the 3IQR criterion for their assigned mood group and data from one participant could not be included because these were incomplete due to technical failure during data collection. All participants gave written informed consent before the start of the study. The study was approved by the ethics committee of the Institute of Psychology of Leiden University.

Materials

Apparatus, sound levels, mood assessment and threshold task were as described for Experiment 1, with the exception that foam ear tips were used for the insert earphones, providing 48 dB external noise attenuation.

Mood induction and assessment

The mood induction method was identical to the method used in Experiment 1 with the exception that imagining of the mood-appropriate event was combined with watching mood appropriate pictures instead of listening to music. The pictures were presented before the imagination task and consisted of twelve pictures per mood condition[1] that were taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). To create the sets of pictures for each of the four mood conditions, pictures were selected based on the average pleasure and arousal ratings (on a scale from 1 [low] to 9 [high]) for women as provided by the IAPS manual (Lang et al., 2005). This resulted in one set of twelve pictures depicting high arousing unpleasant scenes (e.g., dangerous animals and crime scenes); one set of twelve pictures depicting low arousing unpleasant scenes (e.g., funeral scenes, people suffering from old age, incarceration, or poverty); one set of twelve pictures depicting high arousing pleasant scenes (e.g., extreme sports scenes and romantic scenes); and one set of twelve pictures depicting low arousing pleasant scenes (e.g., peaceful nature

[1] IAPS pictures used. Anxious condition: 1120, 1200, 1300, 3071, 3530, 6230, 6370, 6510, 6540, 6570, 6821, 9252; Sad condition: 2490, 2590, 2722, 6010, 9001, 9045, 9090, 9101, 9110, 9190, 9220, 9331; Happy condition: 1650, 4611,5621, 5626, 5629, 8030, 8034, 8080, 8200, 8370, 8470, 8501; Calm condition: 1450, 1610, 1900, 2560, 5030, 5201, 5250, 5593, 5720, 5750, 5800, 7900.

scenes, plants, and flowers). Table 3.4 shows the average ratings of the pictures per mood condition.

Table 3.4: *Average ratings of the IAPS pictures used per mood condition in Experiment 2.*

Mood condition	Pleasure rating $M(SD)$	Arousal rating $M(SD)$
Anxious (Low pleasure, High arousal)	2.30 (0.65)	6.89 (0.34)
Sad (Low pleasure Low arousal)	3.17 (0.58)	3.98 (0.21)
Happy (High pleasure, High arousal)	7.31 (0.64)	6.37 (0.52)
Calm (High pleasure, Low arousal)	6.89 (0.59)	3.16 (0.48)

Note: Ratings are taken from the normative ratings for women in the IAPS manual (Lang et al., 2005).

Experiment Procedure

The only differences in procedure between Experiment 1 and Experiment 2 concerned the mood induction and the inclusion of female participants only. As in Experiment 1 the mood induction procedure started after the second mood rating was obtained. To help them to activate the desired mood state, participants first watched the 12 IAPS pictures, each presented for five seconds on the screen. Next, they proceeded to the writing task, which was identical to the task in Experiment 1. However, in contrast to Experiment 1 there was no music playing in the background. Subsequently they carried out the test threshold task, which had an average duration of $M = 3$ min and 53 s ($SD = 29$ s).

Results

All reported analyses were analyses of variance (ANOVA) or t-tests unless indicated otherwise. For all analyses a significance level of $\alpha = .05$ was used.

Mood induction manipulation check

Figure 3.4 shows the ratings of arousal and pleasure per moment of measurement during the experiment. Participants started out with a fairly neutral mood as reflected in the experienced level of arousal ($M = 4.92$, $SE = 0.16$) and pleasure ($M = 5.48$, $SE = 0.12$) at baseline (SR1). There were no differences in subjective arousal or pleasure at baseline between the groups assigned to the different moods, ps $> .05$.

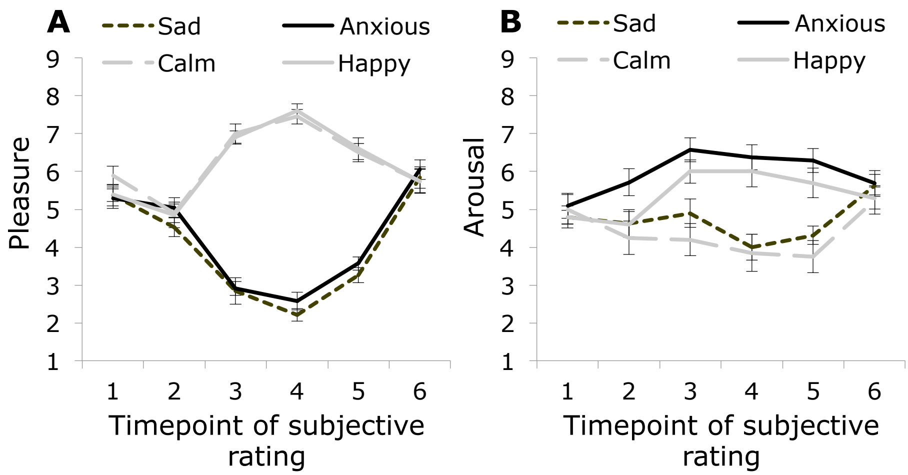

Figure 3.4: Subjective ratings of (A) pleasure and (B) arousal levels during the experiment, per mood group (whiskers are standard errors) for Experiment 2.

Seventy-three percent of the participants indicated that they had used events that really happened for the writing and imagining task carried out during the mood induction procedure and 23% indicated that they used fictional events. During task performance (SR4 and SR5 averaged) the happy ($M = 7.10$, $SE = 0.22$) and calm ($M = 6.98$, $SE = 0.17$) groups experienced more pleasure than the anxious ($M = 3.07$, $SE = 0.17$), and sad ($M = 2.74$, $SE = 0.15$) groups, $F(1,76) = 520.13$, $p < .001$, $\eta_p^2 = 0.87$, $MSE = 0.66$. Arousal ratings were higher for the happy ($M = 5.85$, $SE = 0.33$) and anxious ($M = 6.33$, $SE = 0.32$) groups, than the calm ($M = 3.80$, $SE = 0.33$), and sad ($M = 4.16$, $SE = 0.34$), groups, $F(1,76) = 40.59$, $p < .001$, $\eta_p^2 = 0.35$, $MSE = 2.20$.

Mood and masked threshold

Table 3.5 shows the means and standard errors of the baseline and test thresholds for the different mood groups in dB SPL.

The baseline threshold did not differ between pleasure groups, $F < 1$, or between arousal groups, $F(1,76) = 2.08$, $p = .153$, $\eta_p^2 = 0.027$, $MSE = 4.00$, and there was no interaction between pleasure and arousal, $F(1,76) = 1.99$, $p = .162$, $\eta_p^2 = 0.026$. To reduce error variance, the baseline threshold was added as a covariate, $F(1,75) = 15.63$, $p < .001$, $\eta_p^2 = 0.172$, $MSE = 0.81$, in the analyses of the test threshold. The assumption of homogeneity-of-regression-slopes was

Table 3.5: *Baseline and test threshold (dB SPL) per mood group of Experiment 2.*

Threshold	Mood group			
	Low pleasure		High pleasure	
	Low arousal (Sad) ($N = 19$)	High arousal (Anxious) ($N = 21$)	Low arousal (Calm) ($N = 20$)	High arousal (Happy) ($N = 20$)
	$M(SE)$	$M(SE)$	$M(SE)$	$M(SE)$
Baseline threshold	16.39(0.55)	16.37(0.44)	17.22(0.39)	15.94(0.40)
Test threshold	17.06(0.56)	15.86(0.42)	17.25(0.48)	16.33(0.41)

met, as indicated by the absence of an interaction between baseline threshold, arousal, and pleasure, $F < 1$. The threshold adjusted for the baseline threshold was lower for the high arousal groups (adjusted $M = 16.23$, $SE = 0.31$) than for the low arousal groups (adjusted $M = 17.01$, $SE = 0.31$), but the analysis of covariance (ANCOVA) showed that this effect did not reach significance, $F(1,75) = 3.11$, $p = .082$, $\eta_p^2 = 0.040$, $MSE = 3.75$. There was no effect of pleasure, or an interaction effect of pleasure and arousal, Fs < 1.

To explore whether the relation between the threshold and subjective arousal is consistent with the inverted U-shaped relation between arousal and task performance curve (Aston-Jones & Cohen, 2005; Easterbrook, 1959; Kahneman, 1973), we performed a second-order polynomial sequential regression analysis of the masked auditory threshold on subjective arousal during task performance centered to the mean, and after first regressing out the baseline threshold. The regression model including only the baseline threshold significantly predicted the test threshold, $R^2 = .18$, $F(1,78) = 17.56$, $p < .001$. Improvement of prediction by adding centered subjective arousal did not reach significance, $R^2_{Change} = .033$, $F_{Change}(1,77) = 3.22$, $p = .077$, and further adding of squared centered subjective arousal did not improve prediction $R^2_{Change} = .01$, $F_{Change}(1,76) < 1$. Table 3.6 shows the beta values with standard errors and standardized betas per predictor.

Table 3.6: *Unstandardized regression coefficients (B), standardized regression coefficients (β), and p-values for the regression of test threshold on: baseline threshold (Step 1); baseline threshold and centered subjective arousal (Step 2); baseline threshold, centered subjective arousal, and squared centered subjective arousal (Step 3) of Experiment 2.*

	$B(SE)$	β	p
Step 1			
Intercept	9.07(1.81)		<.001
Baseline threshold	0.46(0.11)	0.43	<.001
Step 2			
Intercept	9.40(1.80)		<.001
Baseline threshold	0.44(0.11)	0.41	<.001
Linear centered arousal	-0.22(0.12)	-0.18	.077
Step 3			
Intercept	9.62(1.82)		<.001
Baseline threshold	0.43(0.11)	0.41	<.001
Linear centered arousal	-0.23(0.12)	-0.19	.064
Quadratic centered arousal	-0.05(0.07)	-0.08	.452

3.4 Combined Results of Experiment 1 and Experiment 2

To explore whether or not the results from Experiment 2 were different from the results of Experiment 1, we combined the data from both experiments and examined if there were any interactions with experiment. Because the values of the (baseline) thresholds differed between Experiment 1 and Experiment 2 (possibly due to use of different material, e.g., ear tips), we used normalized scores. Baseline and test threshold scores were normalized to the baseline threshold of the respective experiment. This was done in the following way: The experiment mean of the baseline threshold was subtracted from the individual test threshold scores and these differences were divided by the experiment standard deviation of the baseline threshold.

Mood induction manipulation check

To check whether the effect of the mood induction affected experienced arousal and pleasure dimensions of the mood differently for both experiments, interactions between mood group and experiment on arousal and pleasure ratings (averaged over SR4 and SR5) were examined.

In addition to a main effect of pleasure, $F(1,148) = 702.55$, $p < .001$, $\eta_p^2 = 0.83$, $MSE = 0.81$, on pleasure experienced during task performance, there was a significant interaction effect between experiment and pleasure, $F(1,148) = 4.70$, $p = .032$, $\eta_p^2 = 0.31$, $MSE = 0.81$. The interaction effect occurred due to lower pleasure ratings in the low pleasure moods in Experiment 2 ($M = 2.9$, $SE = 0.14$) than in Experiment 1 ($M = 3.44$, $SE = 0.14$), $F(1,148) = 7.13$, $p = .009$, $\eta_p^2 = 0.83$, $MSE = 0.81$. There were no differences between experiments for pleasure ratings in the high pleasure moods, $F < 1$. As can be seen from the analyses presented above for each experiment separately, the differences between low and high pleasure moods were large and significant for both experiments.

In addition to the main effect of arousal, $F(1,148) = 210.38$, $p < .001$, $\eta_p^2 = 0.37$, $MSE = 2.40$, on arousal experienced during task performance there was a significant interaction between experiment, pleasure and arousal, $F(1,148) = 4.29$, $p = .040$, $\eta_p^2 = 0.03$, $MSE = 2.40$. This interaction effect was due to the presence of an interaction between pleasure and arousal in Experiment 1 that occurred because the effect of arousal was larger in the high pleasure than low pleasure moods, while such an interaction effect was absent in Experiment 2 (see results for each experiment separate above). There was no main effect of experiment or an interaction effect between experiment and arousal, Fs < 1. Figure 3.5 shows the subjective pleasure and arousal during threshold task performance per mood condition per experiment.

Mood and masked threshold

An ANCOVA was carried out on the normalized test threshold, with standardized baseline threshold as covariate, $F(1,147) = 17.68$, $p < .001$, $\eta_p^2 = 0.107$, $MSE = 0.84$, and experiment, arousal and pleasure as factors. The assumption of homogeneity-of-regression-slopes was met, as indicated by the absence of an interaction between baseline threshold, experiment, arousal, and pleasure, $F(7,140) = 1.31$, $p = .248$, $\eta_p^2 = 0.062$, $MSE = 0.83$. The ANCOVA showed no main effect of arousal, pleasure or experiment, Fs < 1, but did show an interaction between arousal and experiment, $F(1,147) = 10.33$, $p = .002$, $\eta_p^2 = 0.066$, $MSE = 0.84$. This interaction occurred due to opposite effects of arousal in Experiment 1 compared to Experiment 2: In Experiment 1 thresholds were larger in the high arousal than the low arousal groups, while in Experiment 2 thresholds were smaller, albeit not significant, in the high than in the low

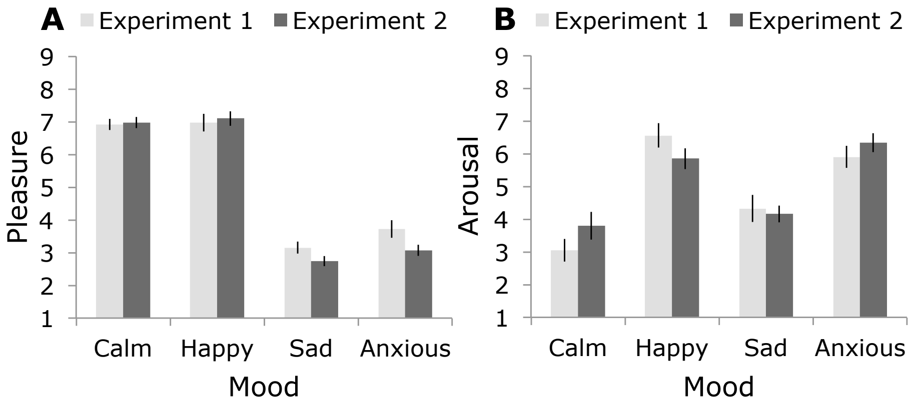

Figure 3.5: Subjective (A) pleasure and (B) Arousal during threshold task performance per mood condition per experiment. Errors bars represent one standard error above and below the means.

arousal groups (see results for each experiment separate above). There were no other interactions with experiment, $F < 1$, but the interaction between pleasure and arousal approached significance, $F(1,147) = 3.71$, $p = .056$, $\eta_p^2 = 0.107$, $MSE = 0.03$. This interaction occurred because the effect of arousal in the low pleasure groups was opposite to the effect of arousal in the high pleasure groups, however both effects of arousal were not significant, $F(1,75) = 1.22$, $p = .272$, $\eta_p^2 = 0.02$, $MSE = 0.98$, and $F(1,75) = 2.42$, $p = .124$, $\eta_p^2 = 0.12$, $MSE = 0.70$, respectively. Figure 3.6 shows an overview of the normalized thresholds adjusted for the standardized baseline threshold per experiment per mood condition.

To explore whether the combined data of Experiment 1 and 2 are consistent with the inverted U-shaped relation between arousal and task performance curve (Aston-Jones & Cohen, 2005; Easterbrook, 1959; Kahneman, 1973), we performed a second-order polynomial sequential regression analysis of the normalized masked auditory threshold on subjective arousal during task performance centered to the mean (of Experiment 1 and 2 together), and after regressing out the standardized baseline threshold. The regression model including only the baseline threshold significantly predicted the test threshold, $R^2 = .10$, $F(1,154) = 17.02$, $p < .001$. Adding centered subjective arousal did not improve prediction of the model, $R^2_{Change} = .001$, $F_{Change}(1,153) < 1$ and neither did further adding of squared centered subjective arousal $R^2_{Change} = .01$, $F_{Change}(1,152) < 1$. Table 3.7 shows the beta values with standard errors and standardized betas per predictor.

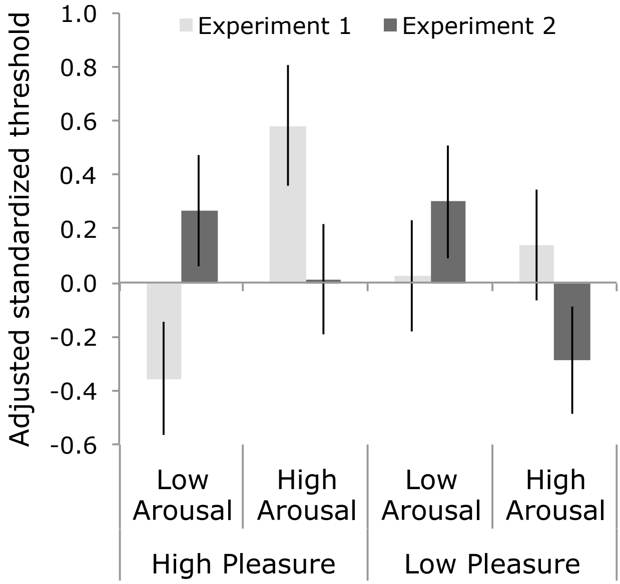

Figure 3.6: Thresholds normalized to the mean and standard deviation of the baseline threshold and adjusted for the baseline threshold per experiment per mood condition. Errors bars represent one standard error above and below the mean.

3.5 Discussion

We investigated the effect of the pleasure and arousal dimension of mood on the masked auditory threshold in two experiments. In Experiment 1 the mood induction procedure was accompanied by music, while in Experiment 2 a visual mood induction procedure was used. Experiment 1 suggested that lower (up to a certain optimum) affective arousal decreased the masked auditory threshold, irrespective of pleasure level. However, as indicated by an interaction effect between experiment and arousal, arousal did not have the same effect in Experiment 2. The effect of arousal in Experiment 2 on the masked auditory threshold did not reach significance but was a trend in the opposite direction to the effect of in Experiment 1. In both experiments no significant effects of the pleasure level were found on the masked auditory threshold. The remainder of the discussion will therefore focus on the effects of the arousal dimension rather than the pleasure dimension of mood on auditory processing.

Although we carefully controlled the music for sound level in Experiment 1,

Table 3.7: *Unstandardized regression coefficients (B), standardized regression coefficients (β), and p-values for the regression of test threshold (normalized to the mean and standard deviation of the baseline threshold) on: baseline threshold (Step 1); baseline threshold and centered subjective arousal (Step 2); baseline threshold, centered subjective arousal, and squared centered subjective arousal (Step 3). Data of Experiment 1 and 2 were combined for this analysis.*

	$B(SE)$	β	p
Step 1			
Intercept	0.08(0.08)		.324
Baseline threshold	0.31(0.08)	0.32	<.001
Step 2			
Intercept	0.08(0.08)		.325
Baseline threshold	0.32(0.08)	0.32	<.001
Linear centered arousal	0.02(0.04)	0.03	.703
Step 3			
Intercept	-0.02(0.11)		.875
Baseline threshold	0.32(0.08)	0.32	<.001
Linear centered arousal	0.02(0.04)	0.03	.697
Quadratic centered arousal	0.02(0.02)	0.09	.223

Experiment 2 was carried out to exclude any possibility of confounding by other acoustic properties of the music used for the mood induction. To this end affective pictures instead of music were used for the mood induction procedure in Experiment 2. Analysis of the self-reported arousal and pleasure experienced during the threshold task after the mood induction showed that the participants in both experiments had the desired mood states during the task. Therefore, if the effects on the threshold found in Experiment 1 were due to differences in arousal, we would also expect these effects in Experiment 2. However, as noted above, arousal had a different effect in Experiment 2; there was a trend in opposite direction to the effect in Experiment 1.

We checked if the finding of opposite directions of the arousal-threshold relation in the two experiments could be explained by a curvilinear relation between arousal and threshold. The presence of a curvilinear relationship was expected based on theories about the relation between arousal and performance in general (Aston-Jones & Cohen, 2005; Kahneman, 1973), and the findings of Experiment 1. The results of Experiment 1 suggested a curvilinear relation between arousal and threshold, which reflected that listeners who reported very low subjective arousal or very high subjective arousal had higher thresholds (lower masked sensitivity) than listeners with a more intermediate (optimal) level. A curvilinear relation could explain opposite effects of arousal on the threshold in the following way: If on average the subjective arousal levels for participants in Experiment 1 fell on the higher side of the optimum, thus on the right side of the U curve, this would be reflected in a positive relation between arousal and threshold. And, if on average the subjective arousal levels for participants in Experiment 2 fell on the lower side of the optimum, thus on the left side of the U curve, this would be reflected in a negative relation between arousal and threshold. This, however, does not seem to be the case. The comparison of subjective arousal scores between the experiments did not reveal a statistically significant main effect of experiment, which suggests that average arousal scores did not differ between experiments. Furthermore, the regression analysis of the threshold for both studies together showed that squared arousal did not significantly improve prediction of the threshold beyond that of the baseline threshold (and linear arousal). Thus, given the distribution of the subjective arousal scores of both experiments and on analyses of the combined experiments, there is no basis to conclude that a U-shaped relation between arousal and the threshold could explain why Experiment 2 showed a trend in opposite direction to the effect of arousal Experiment 1.

Taken together, although the different mood induction procedures had similar effects on subjectively experienced arousal in both experiments, the effect of arousal differed per experiment, as indicated by the interaction effect between study and arousal. Therefore it cannot be concluded that mood induction by music had the same effect as induction using pictures. Instead, the effect in Experiment 1 may have been brought about by differences in the acoustical properties of the music. Studies that systematically investigate the effects of acoustical properties of preceding auditory stimulation on subsequently measured thresholds could shed more light on this possibility.

The inconsistent results of the two experiments may have also been caused by a larger effect of mood induction on subjectively experienced arousal in the high pleasure conditions (i.e., calm versus happy) in Experiment 1 than in Experiment 2 (see Figure 3.5). These numerical differences receive some support from an extra ANOVA of subjective arousal during the threshold in the high pleasure conditions showing that the interaction between arousal and experiment almost reached significance, $F(1,76) = 3.54$, $p = .054$. Also note that a separate ANOVA showed no significant interaction effect between arousal and experiment, $F < 1$, in low pleasure conditions. Although it seems unlikely to fully explain the difference between Experiment 1 and 2, the difference in successfulness of the mood induction between the experiments may at least partly explain the presence of an arousal effect in Experiment 1 and a weaker (trend in opposite direction) effect of arousal in Experiment 2. More complex interactions between mood and other factors associated with differences between the studies may also have occurred. For example, in Experiment 1, due to the use of music, attention may have been focused more on the auditory than the visual modality compared to Experiment 2. This, in turn, may have rendered the masked auditory threshold task differently susceptible to mood effects compared to Experiment 2.

As set out above, in Experiment 1 the threshold significantly differed between the high and low arousal conditions, however this difference may be explained by other factors than arousal per se. While these factors were excluded in Experiment 2, the results of Experiment 2 do not provide conclusive evidence regarding the presence of an arousal effect. Only a marginally significant effect was found. Furthermore, the number of participants for Experiment 2 was determined by a pre-study power analysis based on an effect of similar magnitude as the effect in Experiment 1. A direct replication of Experiment 2 using a much larger number of participants would be necessary to evaluate whether any effects, including small effects, of arousal on the masked auditory threshold are present or not (Brandt et al., 2014; Simonsohn, 2015). In addition to large scale replication of the present study we would like to present additional suggestions for further research into the underexplored topic of affective modulation of basic auditory perception.

Suggestions for further research

First, future studies could explore the effects of brief affective stimuli on the masked auditory threshold. Mood by nature is long in duration, however the effects of a mood induction may wane over time, which limits the duration of the auditory task that can be employed. Brief affective stimuli, such as affective pictures, presented before auditory task stimuli allow researchers to circumvent this limitation. In addition, using brief affect inductions allows for within subject comparison within one session.

Second, future studies may investigate the effects of more extreme affect inductions on the masked auditory threshold instead of mood induction. Although subjective pleasure and arousal ratings showed that our mood manipulation changed people's affective state successfully, mood states are more diffuse and less extreme than other types of affective state, such as the state elicited by the threat-of-shock paradigm. The latter could therefore be more effective in eliciting changes in early perception. Indeed, studies using this more extreme affect method found modulation of a very early stage of auditory processing in the brain (Baas et al., 2006).

Third, future studies may include parametric manipulation of arousal with both extreme and more intermediate arousal conditions. As discussed above, Experiment 1 showed a curvilinear relationship between subjectively experienced arousal and the masked-auditory threshold. However, a similar pattern was not found in Experiment 2, and the relationship in Experiment 1 was based on subjectively experienced rather than experimentally controlled arousal levels. In order to provide more definite conclusions regarding non-linear effects of arousal, for future research it is advisable to include both extreme and intermediate arousal conditions.

Fourth, future studies should employ various tasks tapping into different aspects of early auditory perception. Previous studies showed that improvement of early visual perceptual processing by affect depends on the properties of the stimuli that are processed. For example, Bocanegra and Zeelenberg (2009) and T.-H. Lee, Baek, et al. (2014) demonstrated that brief presentation of fear-inducing stimuli enhanced subsequent processing of low-spatial-frequency visual stimuli, while it impaired processing of high-spatial-frequency visual stimuli. Similarly, modulation of sensitivity of auditory perception is likely to be dependent on the type of stimuli employed. The present study explored effects on the masked auditory threshold for 1 kHz tones using simultaneous energetic masking conditions. Future studies into affective modulation of early auditory perception should also explore effects of affective arousal on various other tasks and stimuli. For example, effects of arousal on simultaneous masking may be compared to effects on backward masking. In a backward masking task the mask is presented directly after the to be detected tone. This task taps into temporal auditory processing and is thought to be more susceptible to cognitive modulation (Strait et al., 2010) and may therefore also be more susceptible to modulation by affective arousal.

Fifth, future research may simultaneously measure affect modulation of bias and sensitivity (in terms of signal detection theory). As set out in the introduction, previous findings of increased perceived loudness in high arousal negative mood (E. H. Siegel & Stefanucci, 2011) could be brought about by increased auditory sensitivity and by mood effects on the criterion for responding and bias judgments. Therefore in the current study we took care to exclude effects of bias by using a 2IFC task, which is designed to provide a measure of perceptual sensitivity (Green & Swets, 1966). This task, in combination with the adaptive procedure, was chosen for its relative time efficiency in order to stay within the duration of the induced mood. However, the task does not allow for statements about the relative contributions of bias and sensitivity to mood modulation of auditory perception. Future studies could measure influences of affective arousal on the masked auditory threshold by means of a signal detection task that provides separate indices of bias and sensitivity.

3.6 Conclusion

Research into affective modulation of auditory processing is still in its infancy. Our study contributed to this field by investigating the effect of mood state on the masked auditory detection threshold, using a presumably criterion free measure of auditory masked sensitivity. Our results showed no significant effect of pleasure level on auditory masked sensitivity. The effect of arousal level depended on the modality of the stimuli (auditory or visual) that were used in the mood induction, which makes it difficult to draw conclusions regarding the question whether the effect of arousal on the threshold is a genuine effect of mood. Future studies should investigate affective modulation of different aspects of audition using different types of affect modulations to elucidate which aspects of auditory processing are susceptible to modulation by affect and which are not.

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4

Perceptual Sensitivity and Response to Strong Stimuli are Related

This chapter is based on: Bolders, A. C., Tops, M., Band, G. P. H., & Stallen, P. J. M. (2017). Perceptual sensitivity and response to strong stimuli are related. *Frontiers in Psychology, 8*(1642). doi: 10.3389/fpsyg.2017.01642

To shed new light on the long-standing debate about the (in)dependence of sensitivity to weak stimuli and overreactivity to strong stimuli, we examined the relation between these tendencies within the neurobehavioral framework of the Predictive and Reactive Control Systems (PARCS) theory (Tops, Boksem, Luu, & Tucker, 2010; Tops et al., 2014). Whereas previous studies only considered overreactivity in terms of the individual tendency to experience unpleasant affect (punishment reactivity) resulting from strong sensory stimulation, we also took the individual tendency to experience pleasant affect (reward reactivity) resulting from strong sensory stimulation into account. According to PARCS theory, these temperamental tendencies overlap in terms of high reactivity towards stimulation, but oppose each other in terms of the response orientation (approach or avoid). PARCS theory predicts that both types of reactivity to strong stimuli relate to sensitivity to weak stimuli, but that these relationships are suppressed due to the opposing relationship between reward and punishment reactivity. We measured punishment and reward reactivity to strong stimuli and sensitivity to weak stimuli using scales from the Adult Temperament Questionnaire (Evans and Rothbart, 2007). Sensitivity was also

measured more objectively using the masked auditory threshold. We found that sensitivity to weak stimuli (both self-reported and objectively assessed) was positively associated with self-reported punishment and reward reactivity to strong stimuli, but only when these reactivity measures were controlled for each other, implicating a mutual suppression effect. These results are in line with PARCS theory and suggest that sensitivity to weak stimuli and overreactivity are dependent, but this dependency is likely to be obscured if punishment and reward reactivity are not both taken into account.

Keywords: sensitivity, overreactivity, discomfort, punishment and reward reactivity, temperament, suppression effect, perception, masked auditory threshold, psychophysics.

4.1 Introduction

It has long been recognized that individuals differ in perceptual sensitivity (Eysenck, 1967; Nebylitsyn et al., 1960). The term sensitivity, however, has multiple meanings. On the one hand sensitivity can be regarded as lower threshold for weak stimuli; on the other hand sensitivity can be conceived as low tolerance or overreactivity to strong stimulation. According to several theorists (Aron & Aron, 1997; Eysenck, 1967; Nebylitsyn et al., 1960) both types of sensitivity arise from the same trait. Thus, individuals with a low perceptual threshold will also have a low level of tolerance for strong stimulation. However, it has also been argued that these two types of sensitivity are independent (Ellermeier et al., 2001; Evans & Rothbart, 2008). To shed new light on this debate we examined the relation between these tendencies within the Predictive and Reactive Control Systems (PARCS) theory (Tops et al., 2010, 2014).

PARCS theory differentiates two types of reactivity: punishment reactivity and reward reactivity. High punishment reactivity to strong stimuli corresponds to low tolerance for strong stimulation such as noises, light flashes, and odors, and a tendency to experience negative affect from it. High reward reactivity to strong stimuli corresponds to a tendency to derive pleasure from strong stimulation. In PARCS theory these two temperamental tendencies overlap in terms of high reactivity towards stimuli in the environment, but oppose each other in terms of the response orientation (approach or avoid) towards these stimuli. Due to this opposing relationship each type of reactivity can suppress (statistically; see MacKinnon, Krull, & Lockwood, 2000) the relation between the other type of reactivity and sensitivity to weak stimuli. In the present study we included measures of sensitivity to weak stimuli and of both types of reactivity to be able to test the predicted suppression effects that follow from PARCS theory. This allowed us to investigate whether PARCS theory provides a suitable framework to better understand the dependencies between perceptual sensitivity to weak stimuli and reactivity to strong stimuli.

Before proceeding to the methodological details of our study we will briefly review theories on sensitivity to weak stimuli and reactivity to strong stimuli and evidence supporting these theories. First we will discuss theories that consider sensitivity to weak stimuli and reactivity to strong stimuli as one trait. Then we will discuss theories that regard both traits as independent. Finally we will discuss PARCS theory and our predictions regarding sensitivity and reactivity based on PARCS theory.

Perceptual sensitivity and overreactivity as one trait

One influential theory that regards sensitivity to weak stimuli and overreactivity to strong stimuli to result from one underlying trait is H.J. Eysenck's personality theory about extraversion and introversion (Eysenck, 1967). According to Eysenck, introverts have higher arousal levels than extraverts, which causes higher cortical excitability in introverts. Due to their higher cortical excitability, introverts respond more strongly to stimulation than extraverts and have lower thresholds for weak stimulation, but they are also more easily over-aroused by strong stimulation. Because each individual tries to maintain an optimal arousal level, introverts are predicted to seek non arousing (social) situations, while extraverts seek situations that are highly arousing (Eysenck, 1967). Questionnaires, such as the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975), are based on this prediction and assess the level of Extraversion-Introversion through questions about (social) strategies to maintain optimal arousal level.

A few early empirical studies related Eysenck's introversion-extraversion personality dimension to sensory sensitivity as measured by threshold performance. S. L. Smith (1968) found that higher introversion was indeed associated with lower auditory thresholds for low frequency tones. In addition, Siddle et al. (1969) obtained a significant negative association between extraversion and visual sensitivity as measured by the inverse of the lower absolute threshold. However, neuroticism, another of Eysenck's personality dimensions, was suggested to be a confounding variable in this study, making it difficult to conclude whether sensitivity arises from extraversion, neuroticism, or from a combination of these two traits. A further limitation of both these studies was that the performance on the psychophysical measures used may have not only depended on actual perceptual sensitivity but also on the criterion for responding. In terms of signal detection theory (Green & Swets, 1966; Macmillan & Creelman, 2005), the criterion for responding reflects how strong the internal signal (e.g., the sensory effect produced by a stimulus) needs to be for an individual to decide that a signal is present. The criterion an individual adopts can differ strongly between situations and tasks and depends, for example, on signal probability or the relative value of correctly detecting or correctly rejecting a signal and the relative cost of missing a signal and falsely reporting a signal. Therefore, Edman, Schalling, and Rissler (1979) carried out a study using a threshold procedure developed to measure sensitivity independent of the response criterion. They found that introverts had lower detection thresholds for electrocutaneous stimulation, but only when they also scored high on neuroticism. Taken together, these studies provide some support for the idea that sensitivity arises from an underlying trait that may also give rise to over-arousal by strong stimulation. However, the personality questionnaires used in these studies only included questions about (social) strategies to maintain optimal arousal and did not ask about over-arousal by strong stimulation directly. This makes it difficult to draw strong conclusions from these studies concerning the relation between sensitivity to weak stimuli and reactivity to strong stimuli.

Another, more recent, theory that regards sensitivity and overreactivity as belonging to one trait is the highly sensitive person (HSP) theory developed by Aron and Aron (1997). Central to this theory is the trait sensory processing sensitivity (SPS). SPS is regarded as an evolutionary beneficial survival strategy. It is characterized by heightened awareness of subtle external and internal stimuli. While beneficial in certain situations, this trait comes with the cost of getting more easily overwhelmed by stimulating or quickly changing environments (Aron & Aron, 1997; Aron, Aron, & Jagiellowicz, 2012). Aron and Aron (1997) developed the HSP scale as a unidimensional scale to assess SPS. In line with the presumption that sensitivity and reactivity arise from the same trait, the HSP scale includes items that measure sensitivity to subtle stimuli as well as the tendency to get overwhelmed by strong stimulation. However, in a critical analysis of the HSP scale Evans and Rothbart (2008) questioned the unidimensionality of the scale and argued that sensitivity to weak stimulation and overreactivity are independent traits.

Perceptual sensitivity and overreactivity as independent traits

To test the unidimensionality of the HSP scale Evans and Rothbart (2008) carried out factor analysis on the HSP scores taken from a sample of 297 undergraduates and compared the factor scores with scores on several scales of the Adult Temperament Questionnaire (ATQ; Evans & Rothbart, 2007). The ATQ is based on a multidimensional approach to temperament that subdivides each central temperamental trait into several sub-traits. It enables fine-grained exploration of relationships between these traits (Derryberry & Rothbart, 1988). Importantly, the questionnaire includes separate scales for assessing sensitivity to low-intensity stimulation and perceptual discomfort (overreactivity) due to high-intensity stimulation. Definitions of these ATQ (sub)scales can be found in Table 4.1.

Factor analysis on the HSP items indicated that the HSP scale consisted of two separate factors. The first factor was strongly associated with ATQ negative affectivity and its discomfort subscale in particular. The other factor correlated highly with ATQ orienting sensitivity and its neutral perceptual sensitivity subscale (Evans & Rothbart, 2008). These results do not support the unidimensionality of the HSP scale. Furthermore Evans and Rothbart (2008) did not find a relationship between neutral perceptual sensitivity and discomfort, between orienting sensitivity and discomfort, or between the two factors of the HSP scale. The absence of these relationships questions the unidimensional view that individuals with high sensitivity to weak stimuli also have high reactivity to strong stimulation.

Other findings that conflict with the unidimensional view were reported by Ellermeier and colleagues (2001). In a group of 61 volunteers they investigated the idea that increased reactivity to noise in the environment is (partly) due to increased auditory acuity. To measure reactivity to noise they used a psychometrically evaluated noise sensitivity questionnaire. Note that the term noise sensitivity in this study referred to a stable personality trait concerning perceptual, cognitive, affective and behavioral reactivity towards environmental noises. Noise sensitivity as measured by this questionnaire does thus not refer to sensitivity to weak stimuli, but can be regarded as measure of reactivity (or discomfort in terms of the ATQ) in the auditory domain. Auditory acuity was measured using several measures, including an adaptive forced-choice measure of the absolute threshold of hearing, which can be regarded an objective psychophysical measure of sensitivity to low intensity stimulation. This measure is of specific interest here because it is similar, although methodologically improved, compared to the measures used in the empirical studies discussed above (Edman et al., 1979; Siddle et al., 1969; S. L. Smith, 1968) that found relations between perceptual sensitivity and extraversion. Ellermeier and colleagues, however, found no significant relationship between their measure of reactivity to noise and auditory acuity, including the threshold of hearing. In line with the conclusions of Evans and Rothbart (2008), this finding suggests that reactivity and sensitivity, at least in the auditory domain, are independent from each other and are not originating from a single trait.

Taken together, there is some evidence supporting the claim that sensitivity to weak stimuli and overreactivity to strong stimuli arise from the same trait (Edman et al., 1979; Siddle et al., 1969; S. L. Smith, 1968). However, other research findings suggest that sensitivity to weak stimuli and overreactivity are independent traits (Ellermeier et al., 2001; Evans & Rothbart, 2008). There is thus disagreement about the relationship between sensitivity to weak stimuli and overreactivity to strong stimuli. A solution may be found in PARCS theory (Tops et al., 2010, 2014). In the next paragraphs we will briefly set out PARCS theory and its predictions regarding the relationship between sensitivity to weak stimuli and overreactivity to strong stimuli. Because in the present study we operationalized constructs of PARCS theory using ATQ scales (Evans & Rothbart, 2007), we will relate these constructs to the labels used in the adult temperament model by Rothbart and colleagues (Derryberry & Rothbart, 1988; Evans & Rothbart, 2007) when we introduce them.

Perceptual sensitivity and overreactivity in PARCS theory

PARCS theory provides an integrative framework for understanding psychological states and traits based on functioning of two major control systems in the brain: the predictive and reactive control system. These systems regulate cognition, autonomic responses, behavior, homeostasis, and emotion. PARCS theory describes temperamental or personality traits as dispositional bias towards the reactive or towards the predictive control systems, which are each adaptive in specific environments and contexts. Predictive temperament, which we will also refer to as high predictivity, is characterized by dispositional bias towards the predictive system. The predictive system controls behavior based on internal models that predict which actions will be effective for reaching goals in a given context and allows planning for future events. Predictive temperaments likely evolved to be adaptive in predictable environments, and predictive control is still deemed adaptive in such environments in modern day life (Tops et al., 2010, 2014). For example, when driving in a familiar city with organized traffic where traffic rules are obeyed one can adopt a largely feedforward approach, following previously learned rules and habits applicable to the current context, and plan behavior based on predictions about the future (such as planning ahead what is the best route to arrive home on time while passing by the cheapest gas station and do the weekly groceries on the way). In such a situation a predictive temperament is thus advantageous. In contrast to predictive temperaments, reactive temperaments are characterized by dispositional bias towards the reactive systems, which control behavior in a momentary fashion through feedback from the continuous stream of external stimuli. Reactive control is adaptive in novel, unpredictable and unstable environments (Tops et al., 2010, 2014). For example when driving for the first time in a foreign city with disorganized, busy traffic where other drivers do not (seem to) comply with traffic rules, one needs to adopt a feedback guided strategy, be constantly vigilant to environmental stimuli, and ready to immediately respond to the rapidly and unexpectedly changing situational demands (such as a car ending up in front of you after suddenly changing multiple lanes). In this situation a reactive temperament, which we will also refer to as high reactivity, is thus more suitable than a predictive temperament.

Crucial to the current study, PARCS theory distinguishes two types of reactive systems: the reactive avoidance system and the reactive approach system. In line with other biopsychological theories of personality and temperament based on research in humans (e.g., Cloninger, Svrakic, & Przybeck, 1993; Corr, 2004; Evans & Rothbart, 2007; cf. J. A. Gray & MacNaughton, 2000), the discrimination of the reactive approach and avoidance systems is inspired on the model of anticorrelated reward- and punishment systems developed by Jeffrey Gray on the basis of animal research (J. A. Gray, 1970, 1989). Individuals with bias towards the reactive avoidance system have a strong drive to process (potentially) aversive stimuli and experience aversion in order to avoid these stimuli. This drive is expressed as elevated anxiety and harm avoidance (Pickering & Gray, 1999). We will refer to dispositional bias towards the reactive avoidance system as high punishment reactivity. In the adult temperament model developed by Rothbart and colleagues this construct is labeled as negative affect. In addition to fear, sadness, and frustration it encompasses discomfort, which, as discussed above reflects aversive responding to strong stimuli (Derryberry & Rothbart, 1988; Evans & Rothbart, 2007). Discomfort can thus be understood as punishment reactivity specifically towards strong sensory stimulation. On the other hand, individuals with bias towards the reactive approach system have a strong drive to process (potentially) appetitive stimuli in order to approach these stimuli. This drive is expressed as elevated reward responsiveness and sensation seeking (Pickering & Gray, 1999). We will refer to dispositional bias towards the reactive approach system as high reward reactivity. This construct is labeled extraversion/surgency in Rothbart and colleagues' temperament model. Besides sociability and positive affect it includes high intensity pleasure, which reflects the tendency to derive pleasure from strong stimuli (Derryberry & Rothbart, 1988; Evans & Rothbart, 2007). High intensity pleasure can thus be regarded as reward reactivity specifically towards strong sensory stimulation. According to PARCS theory, depending on the dispositional bias towards the reactive approach or avoidance system one has, the same stimulus may be experienced differently. When confronted with strong stimuli such as loud music, individuals with high punishment reactivity will have a tendency to experience these stimuli as aversive and to be avoided, that is, as punishment. By contrast, individuals with high reward reactivity will have a tendency to experience these stimuli as pleasurable and to be approached, that is, as reward.

PARCS theory builds on, and somewhat reorganizes the above theories of reactive approach and avoidance systems, additionally based on evidence from brain lesion and neuroimaging studies in humans (Tops et al., 2010, 2014; Tops, Montero-Marín, & Quirin, 2016). Furthermore, as mentioned earlier, PARCS theory adds a predictive system to the model. In contrast to the reactive system that enables immediate, mutually incompatible avoidance and approach responding to novel, urgent punishment and reward stimuli, the predictive system utilizes internal models of effective ways to respond to familiar stimuli and contexts. Those internal models represent relationships between entities, motivations, actions, and outcomes and are formed by prior learning during exposure to similar stimuli (Quirin, Kent, Boksem, & Tops, 2015). When the individual encounters similar situations in the future, integrated experiences stored in the internal model can be recalled and will provide context and perspectives for perception and appraisal of the situation and potential actions. Note that this can also apply to punishments or rewards that have been previously integrated into internal models. When presented with a previously integrated compared to a novel punishment or reward stimulus an individual can more readily and flexibly switch from reactive control, with its narrow focus on the salient stimulus, to predictive control, which is less emotionally reactive and more mindful and provident in nature (Quirin et al., 2015; Tops et al., 2014).

Although the reactive system is specifically equipped for immediate responding to stimuli in rapidly changing environments, this does not mean that it operates without higher levels of cognitive processing. According to PARCS theory both the predictive and the reactive system have attentional and cognitive control functionality, but each has a different mode of processing. Reactive control is feedback guided and includes processes such as orienting, appraisal (i.e., assessment of stimuli in the environment on significance for well-being; Moors, Ellsworth, Scherer, & Frijda, 2013), working memory maintenance, and actively sustained attention such as needed for detection of infrequent stimuli. Predictive control, on the other hand, works in a feed-forward fashion, including processes such as planning for future events and inductive reasoning (Tops et al., 2014). This distinction in reactive and predictive cognitive processes is also reflected in neuroimaging and anatomical data. Cortical areas of the reactive system that regulate reactive reward and punishment systems (Tops et al., 2014), such as the anterior insula (AI) and dorsal anterior cingulate cortex (dACC), receive many projections from limbic and subcortical areas of the reactive punishment and reward systems such as the amygdala and ventral striatum. By contrast, cortical areas of the predictive control system, such as the posterior cingulate cortex and precuneus, receive less such projections but seem to downregulate those areas (Devinsky, Morrell, & Vogt, 1995; Tops & Boksem, 2012).

Integrating the above and other evidence, PARCS theory (Tops et al., 2010, 2014, 2016) suggests that the reactive system and the predictive system tend to inhibit each other, producing anticorrelated activation. At the same time, within the reactive system, the approach and avoidance systems also tend to inhibit each other (J. A. Gray, 1970, 1989). Accordingly, reward and punishment reactivity have in common that both reflect reactive, rather than predictive, temperaments, as both are mediated by reactive systems. At the same time these temperaments oppose each other because, in immediate, reactive action control, each reflects a different action orientation (approach or avoid). Thus, PARCS theory predicts that both reward and punishment reactivity are positively related to reactivity and negatively related to predictivity. It also predicts that reward and punishment reactivity are negatively related to each other. Figure 4.1 shows how, according to PARCS theory, punishment reactivity and reward reactivity relate to each other, and how both of them relate to predictivity. In the next paragraphs, we will further argue how this framework may help to elucidate the relation between sensitivity to weak stimuli and overreactivity (punishment reactivity) to strong stimuli.

The present empirical paper does not provide the space to review all evidence behind PARCS theory (for this we refer to review papers, e.g., Tops et al., 2010, 2014, 2016), however we provide some examples from neuroimaging research that show integrated responding to both aversive and appetitive stimuli in areas that also facilitate processing of weak or ambiguous stimuli. Cortical

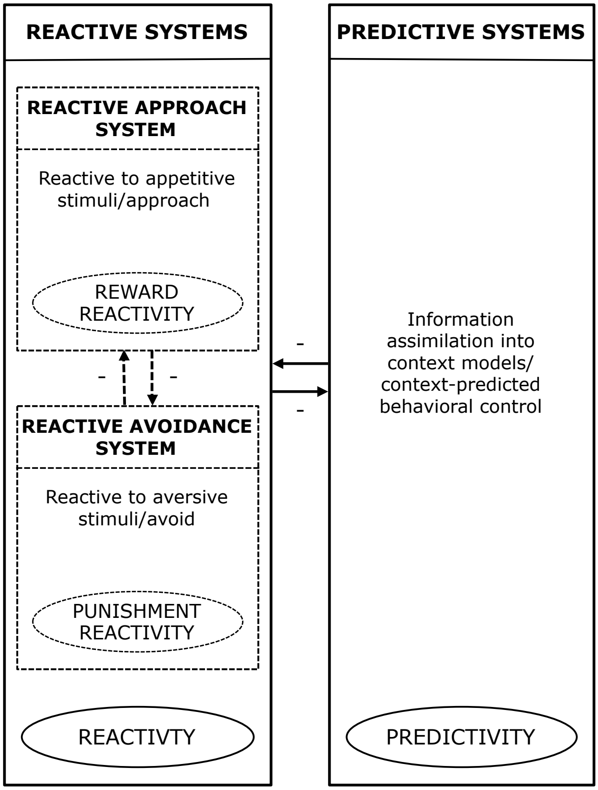

Figure 4.1: Schematic overview of the reactive (approach and avoidance) and predictive systems according to the Predictive and Reactive Control Systems (PARCS) theory. Within the boxes, which represent the systems, we provide a description of characteristic information processing/behavior mediated by the given system. The encircled terms indicate the temperamental tendencies that arise from bias towards the given system. The arrows indicate inhibitory relationships between the reactive systems and predictive systems, and between the reactive approach system and reactive avoidance system.

components of the reactive system in PARCS theory (e.g., the AI and dACC) match what has been named the "salience network" in human neuroimaging studies: a key network in sensory perception and attention allocation (Seeley et al., 2007). Besides receiving projections from networks that seem more strongly involved in either reward or punishment processing, the salience network responds to salient stimuli in general, both appetitive and aversive (Hayes, Duncan, Xu, & Northoff, 2014; Hayes & Northoff, 2012). Moreover, higher connectivity within the salience network was found to be associated with higher individual differences scores of harm avoidance and anxiety (Markett et al., 2013) and decreased connectivity of this network with areas of the reward system was related to decreased extraversion in depressed patients (van Tol et al., 2013). At the same time, the salience network seems involved in processing stimulus salience or relevance to a current task (e.g., detecting a sound) and to be activated whenever sensory input poses a challenge by sensory uncertainty or ambiguity, the disambiguation of which requires enhanced effort and alertness (Lamichhane & Dhamala, 2015; Sterzer & Kleinschmidt, 2010).

The evidence from neuroimaging studies for involvement of the salience network in processing of aversive and appetitive stimuli as well as weak or ambiguous stimuli converges with temperament and personality research. In terms of personality, PARCS theory suggests that trait absorption reflects individual inclinations towards salience network activation (Tops et al., 2016). Absorption is defined as the tendency to get attentionally immersed in and elaborately appraise salient sensory or emotional (positive and negative) experiences and one's internal state (Gohm & Clore, 2000; Tops et al., 2016) and as such correspond to the attentional functions of the reactive system, which include orienting responses and appraisal of salient stimuli. The notion that absorption is a correlate of the salience network in the reactive system is supported by findings that activation of areas in the salience network showed correlation with trait absorption (Tops & Boksem, 2010) and state absorption (Hsu, Conrad, & Jacobs, 2014; Wilson-Mendenhall, Barrett, & Barsalou, 2013). It is also in line with findings that participants scoring high on absorption showed enhanced processing of emotionally neutral task relevant stimulus features as well as enhanced processing of task irrelevant emotional features compared to participants scoring low on absorption. This was reflected in reaction times (RTs) as well as in event related brain potentials (ERPs) to a task in which participants determined whether the letter A, the task-relevant stimulus feature, was present in a word or not. Participants scoring high on absorption responded faster to words with the letter A than without the letter A, while low absorption participants did not show such RT difference. High absorption participants also showed an increased sustained widespread positivity to words containing the letter A, labeled as Late Positive Complex (LPC), compared to low absorption participants, indicating enhanced processing of task relevant features. Furthermore, for high absorption participants only, RT was further decreased and the LPC was further increased when the A occurred in a word with emotional compared to emotionally neutral meaning, indicating that processing of task-irrelevant emotional features was also enhanced for these participants (de Ruiter, Elzinga, & Phaf, 2006; de Ruiter, Phaf, Veltman, Kok, & van Dyck, 2003). Absorption can be measured on various scales (Tops et al., 2016) including the Openness to Experience subscale of personality inventories based on the five factor model of personality (Costa & McCrae, 1992; McCrae & Costa, 1987, 1997). This is supported by studies finding large correlations between openness to experience (especially its fantasy, aesthetics and feelings facets) and other absorption scales, such as the Tellegen Absorption Scale (Glisky, Tataryn, Tobias, Kihlstrom, & McConkey, 1991; McCrae, 1993). Absorption and openness to experience conceptually also strongly overlap with orienting sensitivity in Rothbart and colleagues' temperament model, which is supported by large correlations found between openness to experience and ATQ orienting sensitivity (Evans & Rothbart, 2007; Wiltink, Vogelsang, & Beutel, 2006). In the current study we will therefore use ATQ orienting sensitivity as measure of perceptual and attentional aspects of the reactive system. In comparison to other measures of absorption, the ATQ orienting sensitivity scale is particularly suitable for the present study, because its subscales uniquely focus on orienting to and appraising of weak and subtle stimuli (Evans & Rothbart, 2008). This scale thus provides a measure of sensitivity to weak stimuli that reflects perceptual and attentional aspects of reactivity in PARCS theory.

As reviewed above, both the mutually anticorrelated approach (reward) and avoidance (punishment) systems input to, and activate, the cortical areas of the reactive control system. In turn, the activation of reactive control increases the allocation of attentional resources to aversive and appetitive stimuli, as well as to relevant weak stimuli, which is supported by findings on the perceptual and attentional correlates of trait absorption (de Ruiter et al., 2006, 2003) and the perceptual and attentional correlates of salience network activation (Hayes et al., 2014; Hayes & Northoff, 2012; Lamichhane & Dhamala, 2015; Sterzer & Kleinschmidt, 2010). We therefore expect that orienting sensitivity, as measure of perceptual and attentional aspects of reactivity, positively associates to other measures of sensitivity to weak stimuli, such as sensory detection thresholds. We also expect that orienting sensitivity is related to both the mutually anticorrelated traits of discomfort (punishment reactivity to strong stimuli) and high intensity pleasure (reward reactivity to strong stimuli). In the next paragraph, we will argue more specifically, based on PARCS theory, how taking into account both punishment reactivity and reward reactivity may help to understand the relation between sensitivity to weak stimuli and overreactivity (punishment reactivity) to strong stimuli.

As argued above, based on PARCS theory we predict that perceptual sensitivity is related to both punishment and reward reactivity. However, because the two types of reactivity are also negatively related to each other, they are possible suppressor variables that may cancel out the separate positive relations between each reactivity measure and perceptual sensitivity (MacKinnon et al., 2000). We will illustrate the idea of (statistical) suppression with an example in the auditory domain because the current study included a measure of sensitivity in the auditory domain. PARCS theory predicts that sensitivity to weak sounds, given its association with reactivity, is high in individuals who have a tendency to experience aversion (high punishment reactivity) when exposed to noise or loud sounds and also in individuals who have a tendency to experience pleasure (high reward reactivity) when exposed to noise or loud sounds. At the same time, the tendency to experience aversion due to noise or loud sound is inversely related to the tendency to derive pleasure from it: the more one tends to experience aversion from intense sound the less one tends to experience pleasure from it. Now, take an individual who has a very low tendency to experience aversion from strong sound. On the one hand this person is expected to score relatively low on sensitivity to weak sounds. On the other hand however, this person is also likely to experience strong pleasure from loud sound and therefore is actually likely to score high on sensitivity. If this is the case, extreme scores on both ends of a scale measuring the tendency to experience aversion to strong sounds are associated with high sensitivity. Therefore, across individuals, no positive relationship between deriving displeasure and sensitivity will be observed. This example illustrates that the positive relation between punishment reactivity and perceptual sensitivity can be canceled out due to the negative relation between punishment reactivity and reward reactivity (and vice versa). This type of statistical relationship is known as a suppression effect or inconsistent mediation (MacKinnon et al., 2000). If these suppression effects occur, both types of reactivity will show to be related to sensitivity when controlled for each other, but this relationship is canceled or dampened when not controlled for each other. Thus, according to PARCS theory, in order to gain proper understanding of the relation between sensitivity to weak stimuli and reactivity to strong stimuli, it is crucial to take the suppression effects into account. In the current study we tested the predicted suppression effects.

Current study

As discussed above, in the current study we used (sub)scales of the ATQ to measure punishment and reward reactivity to strong stimuli and sensitivity to weak stimuli, thereby building on the work of Evans and Rothbart (2007, 2008). To summarize, the ATQ discomfort scale measured punishment reactivity to strong stimuli, the ATQ high intensity pleasure (HIP) scale measured reward reactivity to strong stimuli, and the ATQ orienting sensitivity scale measured sensitivity to weak stimuli. Table 4.1 provides definitions and sample items of these ATQ scales.

Table 4.1: *Overview of the main constructs and operational definitions used in the current study.*

Label of construct in the current study	ATQ (sub)scale used to measure the construct, definition of the (sub)scale, and sample item
Sensitivity (for weak stimuli)	**Orienting sensitivity** Tendency for "Automatic attention to both external sensory events and internal events"[1] Includes the subscale **Neutral perceptual Sensitivity** Tendency for "Awareness of slight, low intensity stimulation arising from the external or internal environment. I often notice visual details in the environment"[2]
Punishment reactivity (to strong stimuli) Also: reactive avoidance to strong stimuli, overreactivity, or low tolerance	**Discomfort** Tendency to experience "Unpleasant affect resulting from the sensory qualities of stimulation. I find loud noises to be very irritating"[2]
Reward reactivity (to strong stimuli) Also: reactive approach to strong stimuli	**High intensity pleasure** Tendency to experience "Pleasure related to situations involving high stimulus intensity, rate, complexity, novelty, and incongruity. I would not enjoy the sensation of listening to loud music with a laser light show (coded in reverse)"[2]

[1]Evans, D. E., & Rothbart, M. K. (2008). Temperamental sensitivity: Two constructs or one? *Personality and Individual Differences, 44*, 108-118 (page 111).
[2]Evans, D. E., & Rothbart, M. K. (2007). Developing a model for adult temperament. *Journal of Research in Personality, 41*, 868-888 (Appendix A, page 884-885).

To test the predicted suppression effects we performed a correlational analysis on the ATQ scores. We expected to find a relation between ATQ discomfort and ATQ orienting sensitivity when ATQ HIP would be added as control variable to the analysis, but a weaker, or absent, relation when ATQ HIP would not be taken into account. Similarly, we expected to find a relation between ATQ HIP and ATQ orienting sensitivity when ATQ discomfort would be added as control variable to the analysis, but a weaker or absent relationship when ATQ discomfort would not be taken into account.

Further, building on previous studies investigating the relationship between sensitivity to weak stimuli and traits associated with overreactivity to strong stimuli (Edman et al., 1979; Ellermeier et al., 2001; Siddle et al., 1969; S. L. Smith, 1968) we included a psychophysical measure of perceptual sensitivity in addition to ATQ orienting sensitivity. We chose a measure in the auditory domain because previous studies in this domain yielded mixed conclusions regarding the question whether sensitivity and reactivity arise from the same trait. The inclusion of an objective psychophysical measure is also important because ATQ orienting sensitivity is a rating scale measure of sensitivity to weak stimuli. Rating scale measures may be prone to response bias, which is a "systematic tendency to respond to questionnaire items on some basis other than the specific item content" (Paulhus, 1991, p. 17). There are various types of response biases including social desirability bias, where participants answer in such a way that they give a good impression of themselves regardless of their true characteristics (Furnham & Henderson, 1982; Paulhus, 1991), and extremity bias which is the tendency to give extreme rather than moderate responses (or vice versa) irrespective of the content of the items (Bachman & O'Malley, 1984; Mõttus et al., 2012; Paulhus, 1991). Response bias can impact the magnitude of the means and standard deviations of single scales as well as correlations between scales (Baumgartner & Steenkamp, 2001; Van Vaerenbergh & Thomas, 2013). Including an objective psychophysical measure of sensitivity enabled us to check whether our results could be explained by response bias or not. We used the masked auditory detection threshold for pure tones, which reflects listeners' ability to detect faint sounds in noise, as an objective indicator of sensitivity. To measure it we used a two-interval forced choice (2IFC) procedure combined with a staircase procedure (García-Pérez, 1998). This procedure is regarded as criterion-free, that is, it it is assumed to measure sensitivity without the influence of a response criterion used by the observer (Green & Swets, 1966; Kingdom & Prins, 2010) and thus has minimized vulnerability to effects of response bias. If self-reported sensitivity truly reflects perceptual sensitivity, it should correlate similarly to the reactivity scales as objectively measured sensitivity does. Figure 4.2 shows an overview of the relationships we aimed to test in the current study.

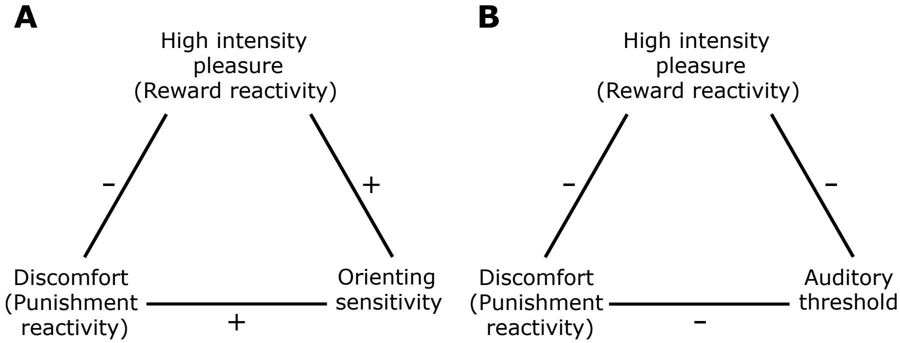

Figure 4.2: Relationships as predicted by Predictive and Reactive Control Systems (PARCS) theory and tested in the current study (A) between discomfort (punishment reactivity), high intensity pleasure (reward reactivity), and orienting sensitivity, and (B) between discomfort, high intensity pleasure, and auditory threshold.

4.2 Method

Participants

Eighty-one participants (Age: $M = 20.5$, $SD = 2.0, 18-27$ years; 20 males) with no self-reported hearing problems or depression took part either for course credit or payment. Data from three participants were not included in the analyses because they had strongly deviating thresholds according to the three interquartile range criterion (3IQR criterion; see section 2.2). All participants gave written informed consent before the start of the study. The study was approved by the ethics committee of the Institute of Psychology of Leiden University. The present study was part of a larger investigation with the same participants on affective and temperamental influences on the masked auditory threshold. Part of this investigation contributed to a study on modulation of the masked auditory threshold by mood state (Bolders, Band, & Stallen, 2017). In the current study only the threshold measured prior to the mood induction was used to examine its relationships with individual differences in temperament.

Apparatus

Sound was binaurally presented through insert earphones (Etymotic ER-4B microPro). These earphones provide 35 dB external noise attenuation. Stimulus presentation was controlled by E-prime 2 software (W. Schneider et al., 2002) using a computer with a CRT screen (75 Hz refresh rate, 1024 x 768 resolution). Responses were made on a QWERTY keyboard and by using a mouse.

Questionnaire

Temperament was assessed using the short version of the ATQ translated into Dutch by Hartman and Majdandžić (2001). This questionnaire consists of 77 items and contains the same constructs and sub constructs as the original ATQ (Evans & Rothbart, 2007). Each item is formulated as a statement. Participants in the current study were asked to indicate how applicable this statement was to them by clicking on the appropriate answer option presented on the computer screen. We used a six-point scale varying from “Not at all” (1) to “Completely” (6). There was also a “not applicable option”, which was treated as missing data point. Appendix 4.A shows the number of items and Cronbach’s alpha per (sub)scale.

Threshold task

Sounds

Two wav files were created with Audacity software, one to serve as a signal and one as non-signal in the threshold task. The signal was a 1 kHz pure tone, 500 ms in duration with 10 ms ramped on- and offset. An empty sound file of 500 ms served as non-signal. A white noise (20 Hz - 10 kHz band-filtered) generated with Goldwave software was used as masking noise that was constantly present during the threshold task. Sound levels at output were calculated from the voltages delivered at the earphone input measured with an oscilloscope (Tektronix TDS2002) and the earphone efficiency reported by the earphone manufacturer (108 dB SPL for 1 Vrms in a Zwislocki coupler, ER-4 datasheet, Etymotic Research, 1992). The white noise was presented with a voltage delivered at the earphone input that would equal 38 dB SPL output for a 1 kHz tone. Digital sound properties for all sounds were standardized (44 kHz, 16 bit, mono).

Task procedure

An adaptive two interval forced (2IFC) choice task was employed to measure the auditory threshold. At the beginning of each trial a fixation cross was presented in the center of the screen for 1000 ms. This was followed by two observation-intervals which were marked with a number presented in the center of the screen (1 or 2). The intervals were separated by a blank interval during which only a fixation cross was presented. The three intervals were each 700 ms in duration. On every trial one of the two observation-intervals was pseudo-randomly selected to contain the signal with the constraint that no more than four trials with the same selected interval could occur in succession. The 500 ms signal was centered in the 700 ms observation interval. After the second observation interval there was a 100 ms blank screen. This was followed by a red “X” presented in the center of the screen until the participants indicated whether they had heard the signal in the first or the second interval by pressing the z-key on the keyboard with their left index finger or the m-key on the keyboard with their right index finger respectively. The sound level of the signals depended on the performance of the participants and increased or decreased adaptively according to a transformed and weighted up/down rule (García-Pérez, 1998). A 1-up/2-down rule was used and the ratio of the step size down and step size up was 0.548. In other words, after one incorrect trial the sound level of the tone went up one step (e.g., 3 dB), but it went down one step only after two consecutive correct trials, with the step size up being 1.82 times the size of the step down. This rule has been shown to reliably converge to 80.35% correct performance (García-Pérez, 1998). Initially the step size down was 15 dB. This changed to 5 dB after two reversal points (trials at which the sound level changed from going up to down or vice versa) and to 3 dB after four more reversal points. The initial sound level was 68 dB SPL. To calculate the threshold (sound level needed for a performance of 80.35% correct) the sound levels of tones at the last ten reversal points were averaged. The E-prime script for the adaptive procedure was adapted from Hairston and Maldjian (2009).

Experiment Procedure

After providing informed consent, participants were seated in a comfortable chair at 50 cm from the computer monitor in a quiet dimly lit individual test cubicle. They were instructed about the flow of the experiment, practiced with correct earphone insertion and the experimenter verified whether external sounds were indeed attenuated. Further instructions followed on the computer screen. Regarding the threshold task it was explained that the signal would be presented equally often in each interval, and that, although the signal could be difficult to hear on some trials, it was important to keep paying attention to the task and that an answer was required on all trials. The task instructions stressed accuracy and all responses were self-paced. Participants carried out eight practice trials in order to get used to the task. The practice trials were equal to the trials of the threshold task, except that the sound level of the signals was kept at 68 dB SPL and after each practice trial participants received feedback about their accuracy. Following the practice trials the threshold task started. At the end of the study participants filled out the ATQ.

Data analyses

Validation analyses

To validate the self-report measure of sensitivity, we correlated the threshold with ATQ orienting sensitivity. ATQ orienting sensitivity includes perceptual sensitivity as a subscale (5 items) but also includes subscales measuring sensitivity to experiencing divergent mental associations or images (5 items) and sensitivity to subtle affective stimuli (5 items). Because ATQ orienting sensitivity is a more reliable (cronbach's α = .67 in current study) measure of sensitivity to subtle stimuli than each of its subscales separately (see Appendix 4.A for cronbach's αs), we used the orienting sensitivity scale in subsequent analyses as self-report measure of sensitivity. It is worth mentioning here that the threshold correlated similarly with each ATQ orienting sensitivity subscale (see Appendix 4.B for correlation coefficients).

Main analyses

To answer our main question about the relation between sensitivity to weak stimuli and reactivity to strong stimuli, we examined the partial correlations between ATQ orienting sensitivity and the perceptual reactivity scales (ATQ discomfort and ATQ HIP). The correlation between ATQ orienting sensitivity and ATQ discomfort was controlled for ATQ HIP and the correlation between ATQ orienting sensitivity and ATQ HIP was controlled for ATQ discomfort. We carried out the same analyses replacing ATQ orienting sensitivity with the masked auditory threshold.

To examine the expected suppression effects we repeated the above described correlational analyses but without controlling for ATQ HIP or ATQ discomfort. If ATQ HIP and ATQ discomfort suppress each other's association with perceptual threshold and sensitivity, then not controlling for the suppressing variable should substantially reduce the correlations.

In all of the main analyses several other variables were controlled for. First, because we were interested in the relationships with the perceptual aspects of punishment and reward reactivity, we controlled for the broader constructs of ATQ frustration and ATQ positive affect. Where ATQ discomfort measures irritability due to intense stimulation (e.g., “I find loud noises to be very irritating”), ATQ frustration measures irritability in general (e.g., “It doesn’t take very much to make me feel frustrated or irritated”). And, where ATQ HIP measures the tendency to experience pleasure due to intense stimuli (e.g., “I would enjoy the sensation of listening to loud music with a laser light show”), ATQ Positive Affect measures the tendency to experience pleasure in general (e.g., “It doesn’t take much to evoke a happy response in me”). We controlled for ATQ frustration because people who indicate on the ATQ discomfort scale that they get irritated from intense stimuli may actually get irritated easily in general, not only by intense stimuli. Similarly, we controlled for ATQ positive affect because people who indicate on the ATQ HIP scale that they derive pleasure from intense stimuli may actually tend to derive pleasure from things more in general, not specifically from intense perceptual stimuli.

Second, we also controlled for sex because this variable has been associated with discomfort, HIP and externalization and internalization (Ormel et al., 2005) and hearing sensitivity (D. Robinson, 1988). Age has also been associated with discomfort or unpleasantness experienced due to high arousal stimuli (Keil & Freund, 2009; Tops & Matsumoto, 2011) and with hearing sensitivity (D. Robinson, 1988). However, the age range was small and adding age as a control variable did not affect the pattern of the correlations. Therefore the analyses are presented without controlling for this variable.

4.3 Results

Validation analyses

To validate the self-report measure of sensitivity, we correlated the threshold ($M = 21.14$ dB SPL, $SD = 1.93$) with ATQ orienting sensitivity. The threshold had a moderate negative relationship with orienting sensitivity, $r = -.31$, $p = .006$. Appendices 4.B and 4.C provide a full matrix of the uncorrected correlations between all subscales (Appendix 4.B) and ATQ scales (Appendix 4.C) and the threshold. Appendix 4.A provides a table with descriptive statistics for the ATQ (sub)scales.

Main analyses

Correlation coefficients and significance levels of the relationships tested for the main analyses are provided in Figure 4.3.

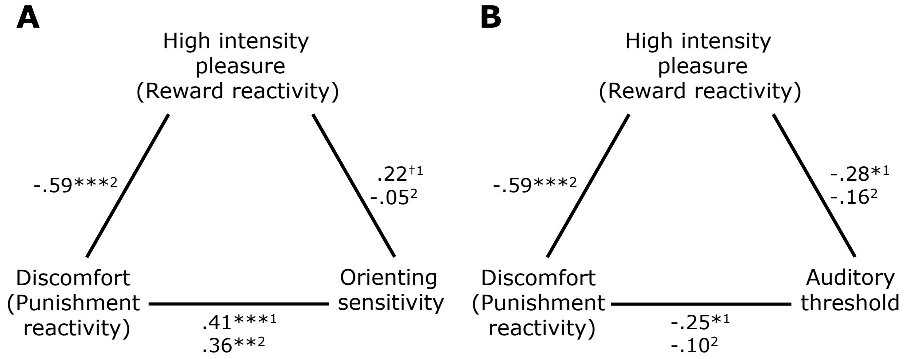

Figure 4.3: Overview of the partial correlation coefficients and significance levels of the relationships (A) between discomfort (punishment reactivity), high intensity pleasure (reward reactivity), and orienting sensitivity and (B) between discomfort, high intensity pleasure, and auditory threshold. [1]Controlled for sex, frustration, positive affect, and HIP or discomfort. [2]Controlled for sex, frustration, positive affect. †$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$.

ATQ orienting sensitivity displayed significant partial correlations with ATQ discomfort and trends of similar magnitude with ATQ HIP when ATQ discomfort and ATQ HIP were controlled for each other and for ATQ frustration, ATQ positive affect, and sex. Similarly, the masked auditory threshold displayed significant partial correlations with ATQ discomfort and with ATQ HIP, when ATQ discomfort and ATQ HIP were controlled for each other and for ATQ frustration, ATQ positive affect, and sex.

When ATQ discomfort and ATQ HIP were not controlled for each other, most correlations between the (self-reported and objective) sensitivity and self-reported reactivity measures were low and not significant. Only ATQ orienting sensitivity still correlated with ATQ discomfort, albeit with slightly lower magnitude.

4.4 Discussion

The present study examined the relations between self-reported and objectively measured sensitivity to subtle stimuli and self-reported reactivity to strong stimulation within the framework of PARCS theory. Importantly, two types of reactivity are distinguished in this theory: punishment reactivity and reward reactivity. We measured punishment reactivity to strong stimulation by means of the ATQ discomfort scale and reward reactivity to strong stimulation with the ATQ HIP scale. Sensitivity to weak stimuli was measured using the objectively determined masked auditory threshold as well as the ATQ orienting sensitivity scale, which is a self-report measure of sensitivity to weak stimuli that reflects perceptual and attentional aspects of reactivity in PARCS theory.

As predicted from PARCS theory, our results showed that ATQ orienting sensitivity was positively associated with objectively determined sensitivity (inverse of the masked auditory threshold). Furthermore, and crucial for answering our research question, both types of reactivity to strong stimulation related to (self-reported and objectively measured) sensitivity to weak stimuli, but only when controlled for each other, indicating a mutual suppression effect. These findings are in line with the notion of PARCS theory that punishment and reward reactivity overlap in terms of reactivity towards stimulation, but that these tendencies also oppose each other in terms of response orientation (approach or avoid). Note that associations between the reactivity measures and self-reported sensitivity to weak stimuli were replicated when sensitivity was objectively measured as the masked auditory threshold, which makes it unlikely that the associations between sensitivity to weak stimuli and the reactivity to strong stimuli were driven by response bias.

Our results may help to understand previous inconsistencies in the literature with respect to the dependency of overreactivity to strong stimuli and perceptual sensitivity to weak stimuli. Some studies found support for the claim that sensitivity to weak stimuli and overreactivity arise from the same trait (Edman et al., 1979; Siddle et al., 1969; S. L. Smith, 1968), while other research findings suggested that sensitivity to weak stimuli and overreactivity are independent traits (Ellermeier et al., 2001; Evans & Rothbart, 2008). Our study demonstrated that when not controlled for reward reactivity to strong stimuli, the relation between punishment reactivity to strong stimuli and perceptual sensitivity might be suppressed. If this is the case, the dependency between punishment reactivity and sensitivity becomes apparent only when reward reactivity is kept constant. Discrepant and zero findings can be expected because differences in the distributions of reward reactivity introduce differences in the relation between punishment reactivity to strong stimuli and sensitivity to weak stimuli. The same holds for the relation between reward reactivity to strong stimuli and sensitivity to weak stimuli when not controlled for punishment reactivity. As previous studies did not take both punishment and reward reactivity to strong stimuli into account, this might explain their discrepant findings regarding the dependency of overreactivity to strong stimuli and perceptual sensitivity to weak stimuli.

Because Eysenck's personality theory (1967) is such a well-known and influential theory that considers sensitivity to weak stimuli and overreactivity to strong stimuli as resulting from one underlying trait, we will specifically compare our results to this theory. Our findings are in line with the ideas of Eysenck in the sense that overreactivity to strong stimuli and sensitivity to weak stimuli seem to be dependent. The pattern of dependencies we found, however, does not agree with Eysenck's predictions, which are based on introversion-extraversion as underlying trait. According to Eysenck, overreactivity to high intensity stimulation is associated with high sensitivity to weak stimulation (Eysenck, 1967). This does match our finding that punishment reactivity to strong stimuli, when controlled reward reactivity, was associated with sensitivity to weak stimulation. Eysenck (1967), however, also suggested that extraverts' enjoyment of high intensity stimulation is associated with low sensitivity to weak stimulation. By contrast, we found that, when controlled for punishment reactivity, pleasure from high intensity stimulation was associated with high sensitivity to weak stimulation. This renders it unlikely that sensitivity to weak stimuli and overreactivity are associated due to introversion-extraversion as underlying trait. Instead, as suggested by PARCS theory the pattern of dependencies can be explained by individual differences in the tendency to activate the salience network of the reactive system. This network mediates processing of aversive and appetitive stimuli as well as relevant weak stimuli, and receives input from both the mutually anticorrelated approach (reward) and avoidance (punishment) reactive systems. Furthermore, as discussed above, our findings stress the importance of taking into account both approach and avoidance reactivity to understand the relationship between sensitivity to weak and overreactivity to strong stimuli. This favors the use of these two dimensions, which are based on Gray's early conceptions of personality (Gray, 1970, 1989) over Eysenck's introversion-extraversion dimension in studying the relation between sensitivity and overreactivity. Moreover, Gray's (1970, 1989) dimensions not only fit better with the current results but also seem to better account for earlier findings. According to J. A. Gray (1970, 1989) punishment reactivity (which he labeled anxiety) is, in terms of Eysenck's personality dimensions, reflected in a combination of high introversion and high neuroticism. Relating sensitivity to punishment reactivity rather than to introversion thus seems to better account for findings of confounding and interaction effects by neuroticism in earlier studies that investigated the relation between introversion and the threshold for noticing weak stimuli (Edman et al., 1979; Siddle et al., 1969).

In addition to furthering the understanding of the relation between sensitivity to weak and reactivity to strong stimuli, our findings also have relevant implications for the study of temperamental and psychophysical determinants of noise annoyance or annoyance produced by other environmental nuisances in daily life. This regards, for example, the question whether noise sensitivity, a measure of discomfort in the auditory domain that predicts noise annoyance, is dependent on basic auditory perception or not (Ellermeier et al., 2001). As our results demonstrated, perceptual reward reactivity (HIP) may suppress the relation between auditory punishment reactivity (discomfort) and perceptual sensitivity. Therefore, in order to gain a more complete picture of the determinants of noise annoyance, we recommend including measures of reward reactivity to strong stimuli in future studies and controlling for it. In addition to noise annoyance, PARCS theory might also provide a framework to contribute to the understanding of other environmental intolerances, such as multiple chemical sensitivity (MCS). MCS, also known as idiopathic environmental intolerance (IEI), is a condition that is characterized by intolerance for chemical agents expressed as various somatic complaints including fatigue, headaches and pain (Bornschein, Hausteiner, Zilker, & Förstl, 2002; Graveling, Pilkington, George, Butler, & Tannahill, 1999). Interestingly, MCS has been associated with anxiety and harm avoidance (Hillert, Jovanovic, Åhs, & Savic, 2013) as well as with absorption (Witthöft, Rist, & Bailer, 2008) which are all indices of reactivity in PARCS theory.

The present study does have some limitations. First, our study had a relatively small number of participants (N = 78). Second, although the ATQ provided suitable measures that have been used in related research before (Evans & Rothbart, 2008), no scales have yet been developed specifically to measure the constructs derived from PARCS theory. Third, our objective measure of sensitivity concerned auditory sensitivity only. Replication of our findings in a large sample using objective measures in other sensory modalities and using a questionnaire based on PARCS theory is important to show robustness and generalizability of these findings. In addition, future studies may also benefit from psychophysical measures of the response to strong stimuli, such as the threshold of pain and objective measures of reward and punishment reactivity such as ERP responses to reward and punishment stimuli during task performance (e.g., Boksem, Tops, Wester, Meijman, & Lorist, 2006; Boksem, Tops, Kostermans, & De Cremer, 2008).

4.5 Conclusion

Taken together, our study showed that self-reported as well as objectively assessed sensitivity to weak stimuli was associated with punishment and reward reactivity to strong stimuli. These relationships only became apparent when the reactivity measures were controlled for each other, indicating a mutual suppression effect. The fact that previous studies did not take this suppression effect into account may explain previous discrepant findings concerning the relation between sensory sensitivity and overreactivity. To conclude, our study indicates that sensitivity to weak stimuli overlaps, at least partly, with the tendency for overreactivity to strong stimuli, in a manner that is in line with the predictions of PARCS theory.

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Appendices

Appendix 4.A: *Descriptive Statistics for the ATQ Scales (in Bold) and Subscales.*

Scale	#items	*M*(*SD*)	skewness	kurtosis	Alpha
Negative Affect scale (ATQ)	**26**	**3.15 (0.57)**	**0.20**	**0.33**	**0.81**
Fear scale (ATQ)	7	2.92 (0.73)	0.20	-0.26	0.63
Frustration scale (ATQ)	6	3.30 (0.82)	0.41	0.41	0.67
Sadness scale (ATQ)	7	3.46 (0.80)	-0.08	0.16	0.74
Discomfort scale (ATQ)	6	2.92 (0.98)	0.56	-0.48	0.78
Effortful Control scale (ATQ)	**19**	**3.56 (0.66)**	**-0.13**	**-0.39**	**0.80**
Activation Control scale (ATQ)	7	3.54 (0.80)	-0.37	-0.61	0.67
Attentional Control scale (ATQ)	5	3.45 (0.89)	-0.18	0.10	0.72
Inhibitory Control scale (ATQ)	7	3.69 (0.73)	0.30	-0.32	0.49
Extraversion/Surgency scale (ATQ)	**17**	**4.17 (0.56)**	**-0.25**	**0.27**	**0.68**
Socialbility scale (ATQ)	5	4.54 (0.84)	-0.47	-0.41	0.70
High Intensity Pleasure scale (ATQ)	7	3.46 (0.95)	0.01	-0.62	0.67
Positive Affect scale (ATQ)	5	4.50 (0.73)	-0.22	-0.28	0.57
Orienting Sensitivity scale (ATQ)	**15**	**3.73 (0.59)**	**0.22**	**-0.11**	**0.67**
Neutral Perceptual Sensitivity scale (ATQ)	5	3.92 (0.73)	0.19	-0.25	0.34
Affective Perceptual Sensitivity scale (ATQ)	5	3.68 (0.82)	0.11	-0.02	0.54
Associative Sensitivity scale (ATQ)	5	3.60 (0.87)	-0.04	-0.61	0.62

Appendix 4.B: *Pearson's Correlation Coefficients Between the Masked Threshold and The ATQ Subscales.*

	Masked Auditory Threshold	Fear	Frustration	Sadness	Discomfort	Activation Control	Attentional Control	Inhibitory Control	Sociability	High Intensity Pleasure	Positive Affect	Neutral Perceptual Sensitivity	Affective Perceptual Sensitivity	Associative Sensitivity
Masked Auditory Threshold	1													
Fear	.047	1												
Frustration	.124	.355**	1											
Sadness	.087	.282*	.154	1										
Discomfort	-.057	.385**	.305**	.192	1									
Activation Control	.076	-.116	-.225*	-.135	.152	1								
Attentional Control	-.041	-.216	-.272*	-.468**	-.194	.464**	1							
Inhibitory Control	.094	-.152	-.342**	-.155	-.067	.518**	.478**	1						
Sociability	-.110	-.193	-.185	-.156	-.178	.259*	.234*	-.056	1					
High Intensity Pleasure	-.152	-.294**	.037	-.312**	-.542**	-.323**	.016	-.172	.165	1				
Positive Affect	-.072	-.176	-.169	-.060	-.094	.283*	.020	.075	.408**	-.052	1			
Neutral Perceptual Sensitivity	-.230*	.035	-.123	.133	.176	.063	-.004	.120	-.002	-.030	-.091	1		
Affective Perceptual Sensitivity	-.212	.119	.002	.341**	.292**	.027	-.244*	.055	.012	-.098	.124	.362**	1	
Associative Sensitivity	-.229*	.006	-.003	.166	.226*	-.142	-.238*	-.212	.034	-.040	.191	.196	.310**	1

** $p < .01$ level
* $p < .05$ level

Appendix 4.C: *Pearson's Correlation Coefficients Between the Masked Threshold and ATQ Scales.*

	Masked Auditory Threshold	ATQ Negative Affectivity	ATQ Extraversion/ Surgency	ATQ Effortful Control	ATQ Orienting Sensitivy
Masked Auditory Threshold	1				
ATQ Negative Affectivity	.066	1			
ATQ Extraversion/ Surgency	-.172	-.450**	1		
ATQ Effortful Control	.047	-.327**	.055	1	
ATQ Orienting Sensitivity	-.308**	.250*	.017	-.130	1

5

Evaluative Conditioning Induces Changes in Sound Valence

This chapter is based on: Bolders, A. C, Band, G. P. H., & Stallen, P. J. M. (2012). Evaluative conditioning induces changes in sound valence. *Frontiers in Psychology, 3*(106). doi: 10.3389/fpsyg.2012.00106

Through evaluative conditioning (EC) a stimulus can acquire an affective value by pairing it with another affective stimulus. While many sounds we encounter daily have acquired an affective value over life, EC has hardly been tested in the auditory domain. To get a more complete understanding of affective processing in auditory domain we examined EC of sound. In Experiment 1 we investigated whether the affective evaluation of short environmental sounds can be changed using affective words as unconditioned stimuli (US). Congruency effects on an affective priming task for conditioned sounds demonstrated successful EC. Subjective ratings for sounds paired with negative words changed accordingly. In Experiment 2 we investigated whether extinction occurs, that is, whether the acquired valence remains stable after repeated presentation of the conditioned sound without the US. The acquired affective value remained present, albeit weaker, even after 40 extinction trials. These results provide clear evidence for EC effects in the auditory domain. We will argue that both associative as well as propositional processes are likely to underlie these effects.

Keywords: evaluative conditioning, affective priming, extinction, valence, environmental sounds, auditory processing

5.1 Introduction

The smell of kerosene, the sound of gulls, and the taste of sea water, although affectively ambivalent, can all attain a positive connotation following a pleasant beach vacation. Likewise, it has been demonstrated with evaluative conditioning (EC) studies that affective evaluation can be modified by pairing the evoking stimulus with affective stimuli (De Houwer et al., 2001; Hofmann et al., 2010). Although the effect has been demonstrated in a variety of conditions and modalities, the change in affective valence of sounds through EC has been scarcely studied (Hofmann et al., 2010, but see Bliss-Moreau, Owren, & Barrett, 2010 for an exception). To investigate whether this effect generalizes to the auditory domain, in the current study short everyday sounds were used in an EC procedure. We tested for the occurrence of effects both on a subjective (explicit) and on an implicit measure. In addition it was investigated whether the acquired evaluation remained stable over repeated presentations of the conditioned stimulus (CS) alone, that is, whether extinction occurred.

Evaluative conditioning can be regarded as a form of conditioning that is specifically concerned with a change in valence of a stimulus (De Houwer et al., 2001; Hofmann et al., 2010; Levey & Martin, 1975). In a typical EC experiment, neutral stimuli are selected, which will function as CS. Then, during an acquisition phase, each stimulus is repeatedly paired with an unconditioned stimulus (US), a stimulus that has a clear positive or negative valence. Finally, the evaluation of the CS is measured in order to establish whether it has changed due to the EC procedure. Importantly, other factors that could change the evaluation, such as mere exposure (Zajonc, 1968) of a stimulus should be controlled for (De Houwer, 2008). A large body of research using the EC procedure and controlling for these factors has demonstrated that EC is a genuine effect that occurs with various types of stimuli under various conditions (De Houwer, 2007; De Houwer et al., 2001; De Houwer, Baeyens, & Field, 2005; Hofmann et al., 2010).

Most studies on EC have used self-report to measure whether the valence of the CS has changed. This way of assessing how people evaluate the stimuli gives them ample time to think about this evaluation and exert control over it. In daily life, however, behavior often arises spontaneously and is therefore guided by evaluations of stimuli in a relatively automatic, rather than controlled manner (De Houwer, 2003, 2006; Fazio & Olson, 2003; Zajonc, 1980). To probe automatic evaluation, implicit measures can be used, such as measures obtained from a speeded categorization task where no explicit reference is made to the valence of the stimulus of interest, but where it does affect performance (Gawronski, 2009). These measures are better suited to predict spontaneous behavior (De Houwer, 2003, 2006; Fazio & Olson, 2003) since the outcome of implicit measures should, according to the normative description of De Houwer, Teige-Mocigemba, Spruyt, and Moors (2009), reflect evaluations in an automatic way (De Houwer, 2006; De Houwer et al., 2009).

In addition, implicit measures are less likely to be influenced by demand characteristics (cues that signal the research hypothesis; Orne, 1962), than self-report measures (Hermans, Spruyt, & Eelen, 2003). In many EC studies it is obvious to the participant that a change in evaluation of the CS is expected, especially when only few CS and US are used (Field, 2005; C. J. Mitchell, Anderson, & Lovibond, 2003). Responses on implicit measures are generally assumed to be difficult to control and this makes them well suited to circumvent the demand problem (De Houwer, 2003; Gawronski, 2009). It has to be noted that recent studies have cast doubt on the full uncontrollability of responses on implicit measures. Under specific conditions, for example when control strategies are provided, participants are able to exert deliberate control on responses to the affective priming task (APT); a widely used implicit measure (Degner, 2008; Teige-Mocigemba & Klauer, 2008). In line with the perspective of Gawronski (2009) we assume that implicit measures may indeed be controllable but much less than subjective ratings.

To assess affective evaluation in the current study we employed an APT. In an APT, a participant is briefly presented with prime stimuli, which potentially trigger an implicit evaluation. After a very short interval the prime stimulus is followed by a positive or negative target stimulus. The participant is asked to quickly classify the valence of the target by pressing one of two response keys. Reaction time (RT) and accuracy effects in the APT reflect the response tendency induced by the prime. Responses will be faster and have higher accuracy when prime and target are of the same valence (congruent) than when they are of opposite valence (incongruent). Thus, the evaluation of the prime can be inferred from these facilitation or interference effects (De Houwer et al., 2009).

Several previous studies have applied the APT to demonstrate EC effects by using the conditioned stimuli, such as human faces (Hermans, Baeyens, & Eelen, 2003), pseudo words (Aguado, Pierna, & Saugar, 2005), and vocal signals (Bliss-Moreau et al., 2010) as prime. Likewise, conditioned sounds will be employed as primes in an APT in the present study. Congruence effects on this task demonstrate that the acquired evaluation of the sounds manifests relatively automatically. To our knowledge, the current study was the first to use the APT with environmental sounds. In contrast to visual information as mostly used in the APT, auditory information is not instantaneous but builds up over time. The APT effect is known to be sensitive to timing parameters of the prime and target (Hermans, De Houwer, & Eelen, 2001; Hermans, Spruyt, & Eelen, 2003), which may thus differ for visual and auditory information. Therefore, we included trials with pre-rated positive and negative sounds of similar length as the conditioned sounds. If affective priming effects are found with these sounds, it validates the use of APT as a measure of sound evaluation (De Houwer et al., 2009). In addition this allows for a comparison of priming effects of the conditioned stimuli with those of the pre-rated positive and negative sounds. Furthermore, recently several studies have indeed demonstrated affective priming effects with various types of affective auditory stimuli (e.g., Goerlich et al., 2012; L. D. Scherer & Larsen, 2011), which strengthens the idea that the APT is a valid measure of sound evaluation.

5.2 Experiment 1: EC effect

The experimental procedure of the first experiment consisted of several phases. During the CS selection phase participants rated a set of sounds and the sounds rated most neutrally were selected as CS. These sounds were paired with positive, negative or neutral words (US) during the conditioning phase and were used as primes in an APT in the affective priming phase. In addition, ratings of the CS were acquired during the post EC rating phase. Given previous findings of EC effects we expected more positive subjective ratings for sounds paired with positive than with neutral US and more negative ratings for sounds paired with negative than with neutral US. Likewise, we expected to find priming effects due to the changed liking of the CS on the APT.

Materials and Methods

Participants

Twenty-four Dutch speaking participants (Age: $M = 21.4$, $SD = 2.6$, $18-29$ years; one male; five left handed) with self-reported normal hearing took part in the experiment for which they received course credits or € 6.50. All participants signed an informed consent form before the start of the study. The study was approved by the ethical committee of the Institute of Psychology of Leiden University.

Materials

Apparatus Stimulus presentation was controlled by E-prime 2.0 software (W. Schneider et al., 2002) using a computer with a CRT screen (100 Hz refresh rate, 1024 x 768 resolution). Sounds were binaurally presented through insert earphones (Etymotic ER-4B microPro) which provide 35 dB external noise attenuation. Responses were made on a QWERTY keyboard and by using a mouse.

Sounds Sounds came from various sources and had all been used in previous research (Bradley & Lang, 2007; Fabiani, Kazmerski, Cycowicz, & Friedman, 1996; Gygi, Kidd, & Watson, 2007). For all sounds, digital sound properties were standardized (44 kHz, 16 bit, mono). The length of the sounds adopted from Fabiani et al. (1996) was left unchanged, while sounds from the International Affective Digitized Sounds (IADS; Bradley & Lang, 2007) and Gygi et al. (2007) were cut to short clips at natural breaks in the sound or with 5 ms ramped off-set to minimize clicks. The sounds reflected events from various sources (e.g., animals, music, nature, human non-verbal vocalizations, mechanical machines, and computers). All sounds were rated previously in a separate sound rating study ($N = 15$, age: $18-30$, normal hearing, Dutch speaking) on a computer-administered pictorial nine-point self assessment-manikin valence scale (SAMv; Bradley & Lang, 1994) ranging from very unpleasant (1) to very pleasant (9).

A set of 18 sounds with ratings close to neutral (valence: $M = 4.94$, $SD = 0.50$; duration: $M = 312$, $SD = 70$ ms) was used for the CS selection phase. Based on individual SAMv ratings made during the CS selection phase of the present experiment, six sounds rated closest to neutral were selected by the computer program for further use during the experiment. Three of these sounds were randomly assigned to serve as CS and subsequently as primes for the APT. Two additional pre-rated sounds served as primes in the semi-experimental validation trials of the APT; the sound of a bird chirping, which was rated as positive and the sound of a gunshot, which was rated as negative. Finally, four sounds were selected to serve as practice sounds in the CS selection phase and in the APT (valence: $M = 5.30$, $SD = 1.43$; duration: $M = 304$, $SD = 118$ ms). More details about the duration, SAMv ratings and the source of all used sounds can be found in Appendix 5.A.

Words All words used in the EC phase and the affective priming phase were chosen from the word norms of Hermans and De Houwer (1994) that provide ratings of 740 Dutch words on affect (1 = very negative; 7 = very positive) and familiarity (1 = not familiar at all, 7 = very familiar). All words were presented in a black 18 point Courier New Font on a white background.

Two sets (set A and set B) each consisting of 15 nouns were selected to serve as US. Each set consisted of subsets of five positive, five negative and five neutral words. Words from one of the two sets were used as US. This was counterbalanced across participants. The subsets of the same valence in set A and set B were matched for affect, affective extremity (extent to which the rating deviated from neutral score 4), familiarity, and word length (in characters). The positive, negative, and neutral word sets differed in rated affect. Positive and negative word sets were matched for affective extremity while ratings of neutral words were lower than of positive and negative sets on this measure. The three word sets were matched for familiarity, and word length. Means for affect, affect extremity, familiarity, and word length per valence category are shown in Table 5.1. Specifications of each word can be found in Appendix 5.B.

Twelve positive and 12 negative adjectives were selected to serve as targets in the APT. Positive and negative word sets differed on affect but were matched for affective extremity, familiarity and word length. Specifications of individual words can be found in Appendix 5.C.

Table 5.1: *Means (SDs) for affect, affect extremity, familiarity and word length of words used per valence category.*

Test phase	Valence	Affect	Familiarity	Affect Extremity	Word length (characters)
EC	Positive	6.02 (0.32)	5.06 (0.59)	2.02 (0.32)	5.60 (1.26)
	Negative	1.95 (0.35)	4.86 (0.35)	2.06 (0.35)	5.30 (1.06)
	Neutral	4.03 (0.09)	4.85 (0.67)	0.08 (0.06)	5.40 (1.35)
APT	Positive	5.99 (0.24)	6.02 (0.29)	1.99 (0.24)	7.50 (2.35)
	Negative	2.02 (0.26)	6.01 (0.34)	1.98 (0.26)	7.75 (2.31)

Note. Scores of affect (1 = very negative; 7 = very positive) and familiarity (1 = not familiar at all; 7 = very familiar) are taken from Hermans and De Houwer (1994). Affect extremity = extent to which the scores deviated from neutral (score 4); EC = evaluative conditioning phase; APT = affective priming task.

Procedure

Upon arrival, participants were guided to a dimly lit individual test cubicle and were seated at 50 cm from the computer monitor, where further instructions were provided. In order to reduce demand characteristics, the study was introduced as a study on the influence of sounds on memory for words.

CS selection phase Participants were presented with 18 sounds and were asked after every sound to rate how pleasant they experienced it by clicking on a nine-point SAMv scale. It was stressed that they should rely on their direct, personal experience and that there were no correct or wrong answers. Before the start of the CS selection task, four practice sounds were rated to familiarize the participants with the type of sounds that would be presented and to the way of rating them. The sound ratings collected during the selection phase were used as baseline measures and to select sounds to serve as CS.

Evaluative conditioning phase Participants were instructed that they would be presented with words and sounds to which no direct response was required, but that they should allow the words and sounds to affect them. They were told that this would be important for a later part of the study.

During the EC procedure each sound was repeatedly paired with words of the same valence type (positive, negative or neutral). Three sounds were paired with supra-optimally presented words (presented long enough to allow for conscious awareness) and the three remaining sounds were paired with sub-optimally presented words (presented short enough to make conscious awareness unlikely for most participants). For each sound five different words were used as US, which were presented four times, resulting in 20 trials per sound. The order of the trials and conditions was randomized.

A trial started with a warning text (“attention!”) which was presented for 2 s, immediately followed by the presentation of a CS sound, during which a fixation cross appeared on the screen. The US word replaced the fixation cross directly after the offset of the sound and remained on the screen for 540 ms. The response-stimulus interval was 1 s. In the trials with sub-optimal US presentation, the fixation cross was replaced by a letter string as forward mask for 250 ms, followed by 40 ms US word presentation and thereafter the same letter string as backward mask of 250 ms. No EC effects were found on any of the measures for sounds paired with subliminally presented words, which is in line with the results of the meta-analysis by Hofmann et al. (2010). The discussion of the absence of the EC effect for subliminal US presentation falls outside the scope of the main research questions in this paper. Therefore, in the present paper only parameters and results related to the supra-optimally presented words and sounds paired with these words are discussed in detail.

Affective priming phase Before the start of the APT the participants were told that they would again hear a sound followed by a word. They were instructed to judge whether the word was positive or negative by pressing the z-key on the keyboard with their left index finger or the m-key on the keyboard with their right index finger. The assignment of valence to the keys was counterbalanced across participants. It was stressed that they should concentrate on the judgment of the word and not on the sound and that they should try to give their response as fast and accurately as possible.

Each trial started with a fixation cross presented in the middle of the screen for 1900 ms, which was followed by a blank screen. The prime sound was presented 100 ms after the onset of the blank screen. The target word appeared on the screen 300 ms after sound onset and remained there until the participant responded or 2000 ms had elapsed. A blank screen was presented during the response-stimulus interval of 2000 ms that followed. Timing of prime, target, response window, and response-stimulus interval were patterned after previous studies using APT to measure acquired evaluation (Aguado et al., 2005; Hermans, Spruyt, & Eelen, 2003).

The APT consisted of 192 trials in which eight prime sounds (three CS sounds that had been supra-optimally conditioned, three sounds that had been sub-optimally conditioned, one positive and one negative pre-rated sound) were presented with each of the 12 positive targets and with each of the 12 negative targets. The order of the trials was randomized. An obligatory break of at least 3000 ms was inserted halfway through the task. In order to get used to the task and to the target words the participants carried out 24 practice trials in which all target words were presented once. During practice, feedback was provided on the screen after the trials in which the participants did not respond within 2000 ms after target onset ("try to respond faster!") or when they incorrectly judged the valence of the target word ("alas, wrong response!"). No feedback was provided during the actual APT.

Post EC subjective valence rating phase After completing the APT participants again listened to the six CS sounds and rated after each sound how pleasant they experienced it by clicking on nine-point SAMv scale. Beforehand it was stressed that they should rate their current experience and that this might have changed or might have remained the same as compared to their previous rating. Further instructions were similar to those for the ratings in the CS Selection phase.

Results

Inspection of box plots of the RTs per person per condition of the APT revealed that one participant responded consistently slower than the others, with values more than 1.5 times the interquartile range (IQR; see section 2.2) above the third quartile in 3 (all consisting of congruent trials) out of 16 conditions. Therefore the data of this participant were discarded from all analyses.

Unless indicated differently, all performed analyses were repeated measures analyses of variance (ANOVA) or paired t-tests. For all analyses a significance level of $\alpha = .05$ was used. In case of violation of the sphericity assumption, as indicated by Mauchly's sphericity test, the degrees of freedom were corrected using the Greenhouse-Geisser (GG) procedure. With regard to the APT results, trials with RT> 2000 ms (0.6%) were discarded from analyses. RTs of trials on which the participant incorrectly judged the valence of the target word (2.9%) were excluded as well.

APT validation with pre-rated primes

Table 5.2 shows performance scores for the APT trials with the pre-rated primes. An ANOVA on mean RT with the factors Congruence (congruent, incongruent) and Target Valence (positive, negative) revealed a main effect of Congruence, $F(1,22) = 5.33$, $MSE = 2503.27$, $p = .031$, $\eta_p^2 = 0.20$, no effect of Target Valence, $F(1,22) = 1.22$, $MSE = 3697.07$, $p = .281$, $\eta_p^2 = 0.05$, and no interaction, $F(1,22) < 1$.

An ANOVA of accuracy showed no effect of Congruence, $F(1,22) < 1$, or of Target Valence, $F(1,22) = 2.48$, $MSE = 14.89$, $p = .129$, $\eta_p^2 = 0.10$, and no interaction effect, $F(1,22) = 3.04$, $MSE = 20.11$, $p = .095$, $\eta_p^2 = 0.12$. This indicates that the effect of congruence on RT cannot be attributed to a speed-accuracy tradeoff.

APT with CS as primes

Mean RT and accuracy on the APT trials with CS as primes are shown in Table 5.2. An ANOVA on RT with the factors Congruence (congruent, incongruent, neutral) and Target Valence (positive, negative) showed an effect

Table 5.2: *Mean (SD) of reaction times (ms) and accuracy (percentage correct) for the APT on the congruent, incongruent and control trials per level of target valence.*

Sound	Condition	Targets			
		Reaction Time		Accuracy	
		Negative	Positive	Negative	Positive
Pre-rated	Congruent	645 (139)	628 (116)	98.2 (3.5)	98.6 (3.2)
	Incongruent	664 (132)	655 (139)	98.9 (2.9)	96.0 (7.1)
CS	Congruent	650 (122)	635 (115)	97.5 (5.9)	96.7 (6.0)
	Incongruent	664 (137)	666 (130)	95.3 (8.6)	93.5 (7.9)
	Control	643 (126)	623 (108)	98.9 (2.9)	97.8 (5.2)

of Congruence, $F(2,44) = 6.26$, $MSE = 1982.42$, $p = .004$, $\eta_p^2 = 0.22$, but no effect of Target Valence, $F(1,22) = 1.85, MSE = 2237.03$, $p = .187$, $\eta_p^2 = 0.08$, and there was no interaction, $F(2,44) < 1$. As expected, responses were slower in the incongruent than in the congruent, $t(22) = 2.08$, $p = .050$, and the neutral condition, $t(22) = 3.23$, $p = .004$. However, responses were not faster in the congruent than in the neutral condition, $t(22) = 1.46$, $p = .160$.

An ANOVA of accuracy revealed a main effect of Congruence, $F(2,44) = 5.69$, $MSE = 33.82$, $p = .006$, $\eta_p^2 = 0.21$, reflecting less correct trials in the incongruent than in the neutral, $t(22) = -3.15$, $p = .005$, and the congruent condition, $t(22) = -2.00$, $p = .059$, but no difference between congruent and neutral trials, $t(22) = -1.32$, $p = .200$. There was neither a main effect of Target Valence, $F(1,22) = 1.43$, $MSE = 35,75$, $p = .244$, $\eta_p^2 = 0.06$, nor an interaction, $F(2,44) < 1$. This indicates that the effects of congruence cannot be attributed to a speed-accuracy trade-off.

A separate ANOVA without neutral trials, with Congruence (congruent, incongruent) and Prime Valence (positive, negative) as factors showed an effect of congruence on RT, $F(1,22) = 4.30$, $MSE = 2663.35$, $p = .050$, $\eta_p^2 = 0.16$, but no effect of Prime Valence, $F(1,22) < 1$, and no interaction, $F(1,22) < 1$. That is, conditioning effects occurred for both negative and positive conditioned sounds.

Another separate ANOVA was carried out without neutral trials but including the trials with pre-rated primes, with Congruence (congruent, incongruent), Target Valence (positive, negative) and Prime Type (CS, pre-rated) as factors. This showed an effect on RT of Congruence $F(1,22) = 7.53$, $MSE = 3286.06$,

$p = .012$, $\eta_p^2 = 0.21$, but no differences between trials with positive and negative targets $F(1,22) = 1.68$, $MSE = 4724.11$, $p = .209$, $\eta_p^2 = 0.07$, and no difference between trials with pre-rated primes and CS primes $F(1,22) < 1$, nor any interaction all $F(1,22) < 1$. The absence of an interaction between Congruence and Prime Type shows that effects of Congruence did not differ between trials with pre-rated primes and CS primes.

Subjective valence rating

In addition to the implicit measure of the conditioning effects, it was investigated whether conditioning was also reflected in subjective ratings. The subjective ratings for conditioned sounds depended on the interaction of the moment of measurement (baseline, post EC) and US valence (positive, negative, neutral), $F(2,44) = 5.04$, $MSE = 1.18$, $p = .011$, $\eta_p^2 = 0.19$. At baseline (CS selection phase), ratings did not differ between the sounds that were to be paired with positive ($M = 5.00$) negative ($M = 5.09$) or neutral ($M = 5.00$) words, $F(2,44) < 1$. However, after the EC procedure there was a difference of negative ($M = 4.09$) versus neutral conditions ($M = 5.17$), $t(22) = -3.22$, $p = .004$. There was no difference of positive ($M = 5.30$) versus neutral conditions, $t(22) = 0.25$, $p = .806$.

Discussion Experiment 1

In Experiment 1 affectively neutral environmental sounds were paired with positive, negative, or neutral words according to a standard EC procedure. After this procedure the affective value of the conditioned sounds was measured by means of an APT, in which the CS served as prime, and by subjective rating. Because this was the first study to use environmental sounds as primes in an APT, validation trials with pre-rated positive and negative sounds as primes were included to check whether priming effects occurred with the current task parameters. Affective priming effects were found on these trials as expected. This indicates that the APT as used in the current study, is a valid measure of sound evaluation (De Houwer et al., 2009).

Changes in evaluation due to the conditioning procedure were indeed reflected as an interference effect in the APT. Responses to targets preceded by affectively incongruent CS primes were slower than to targets preceded by affectively congruent or neutral CS primes. This demonstrates that the affective value did change due to the EC procedure and that these changes were automatically reflected in behavior. This was the case for both the positive and negative conditioned sounds. Furthermore, there was no difference in the priming effect between trials with CS as primes and pre-rated sounds as primes, which indicates that recently acquired evaluation of environmental sounds is equally strongly reflected in behavior as well-established evaluations. The subjective ratings reflected the EC effect for sounds paired with negative words only.

Taken together, these results indicate that the affective value of short environmental sounds can be changed in negative direction, and to a lesser extent in positive direction through EC.

5.3 Experiment 2: Extinction

The first study demonstrated that the affective value of environmental sounds can be changed by means of an EC procedure. A second important issue is whether these changes remain stable over repeated presentations of the conditioned sound alone, that is, whether extinction occurs.

Different theoretical notions of EC generate different predictions about the impact of extinction procedures on the (magnitude of) the acquired evaluation. For example, it has been argued (Baeyens, Eelen, Crombez, & van den Bergh, 1992; Baeyens, Vansteenwegen, & Hermans, 2009), that EC is a form of referential learning in which associations are formed automatically as a result of the co-occurrence of the CS and US. After the association has been established, activation of the CS will activate a representation of the US which, unlike in other forms of conditioning, is not accompanied by the expectancy that the US will occur. Since it is not the expectancy of the US occurrence but the mere association with the US that generates the evaluative response to the CS, EC should be resistant to extinction procedures. Repeated presentation of the CS without a subsequent US should thus leave the acquired evaluation unaffected (Baeyens, Díaz, & Ruiz, 2005).

Opposite predictions are made by accounts that propose that the process underlying EC is the same as the process underlying (other forms of) Pavlovian conditioning (Lipp, Oughton, & LeLievre, 2003; Lipp & Purkis, 2005, 2006). Pavlovian conditioning is generally regarded as a form of signal learning in which propositions are formed about CS-US contingencies. After conditioning, the CS signals the occurrence of the US and the CS is evaluated according to the valence of the US. During extinction the propositions about CS-US contingency are updated and CS evaluation changes accordingly (De Houwer, 2007; De Houwer et al., 2005). These accounts do not predict that EC is resistant to extinction (Lipp & Purkis, 2005).

So far studies examining the role of extinction in EC have yielded mixed results, several studies report that the evaluation of the CS remains stable after an extinction procedure (Baeyens, Crombez, Van den Bergh, & Eelen, 1988; Baeyens et al., 2005), while others found that the evaluations returned to neutral during extinction (Lipp et al., 2003; Lipp & Purkis, 2006). A recent meta-analysis suggests that the EC effect does not disappear after repeated presentation but does decrease compared to the effect measured directly after conditioning (Hofmann et al., 2010).

Proponents of the single process account for EC and Pavlovian conditioning have suggested that findings of resistance to extinction can be attributed to the way in which ratings of the evaluations of the CS were obtained (Lipp & Purkis, 2006). In most studies that found resistance to extinction, CS ratings were collected only at the end of the acquisition and extinction phase of the experiment. According to Lipp and Purkis (2006), when judgments are obtained at the end of the extinction phase only, instead of in the course of the whole experiment, people tend to integrate information about the CS across the acquisition and extinction phases. Therefore these judgments may not reflect actual current stimulus evaluation.

Given the unresolved issues concerning the process of EC and its resistance to extinction it is important to thoroughly investigate whether the evaluation acquired during conditioning remains stable over repeated presentations of the conditioned sound alone. Therefore, in the second study we used a conditioning procedure followed by a substantial number of extinction trials while repeatedly asking people for their judgments.

As in Experiment1, the experimental procedure of Experiment 2 consisted of several phases. The CS selection phase and conditioning phase were identical to those in the first study, except for an additional CS rating after 10 CS-US parings. The conditioning phase was followed by an extinction phase in which the CS were presented without the US. Ratings of the CS during the extinction phase were acquired after every 10 presentations of all conditioned sounds. Given the conflicting findings from previous studies with respect to the effect of extinction procedures, we had no clear expectations about the stability of the acquired evaluations of the CS during and after extinction.

Materials and Methods

Participants

Twenty-four Dutch speaking participants (age: $M = 20.9$, $SD = 3.3$, $18-30$ years; four male; two left handed) with self-reported normal hearing took part in the experiment for which they received course credits or € 6.50. All participants signed an informed consent before the start of the study. The study was approved by the ethical committee of the Institute of Psychology of Leiden University.

Materials

Apparatus, sounds and words for the conditioning phase were identical to those of Experiment 1.

Procedure

Conditioning phase Up to the evaluative conditioning phase the procedure was identical to the first experiment, with the exception that participants were asked to rate the pleasantness of each CS on the nine-point SAMv scale after each CS had been paired 10 times with an US. Instructions for CS rating were the same as in study one. The CS rating was repeated after another 10 CS-US pairings for each CS. This was followed by an assessment of contingency awareness to assess the differences in awareness of CS-US contingencies between EC with sub-optimally and supra-optimally presented US words, which will not be discussed in the current paper.

Extinction phase After the contingency awareness assessment participants were told that they would again hear the sounds repeatedly. They were instructed to concentrate on the sounds and they were informed that they would be asked to rate the sounds four times during this part of the experiment. Sound ratings were collected in the same manner as during the conditioning phase. In total there were six moments of measurement (MM) during the conditioning and acquisition phases (see Figure 5.1). The last rating was again followed by a contingency awareness assessment.

Results

Inspection of box plots of the SAMv ratings per person per CS per MM revealed that one participant rated all sounds as very unpleasant at baseline and these ratings exceeded the 3 inter quartile range criterion (3IQR criterion; see section 2.2). Therefore the data of this participant were excluded from analysis.

Unless indicated differently, all performed analyses were repeated measures ANOVAs or paired t-tests. For all analyses a significance level of $\alpha = .05$ was used. In case of violation of the sphericity assumption, as indicated by Mauchly's sphericity test, the degrees of freedom were corrected using the Greenhouse-Geisser procedure.

Evaluative conditioning effect

Firstly it was tested whether the EC effect occurred looking at the baseline CS rating and the CS rating at the end of the conditioning phase. The ratings depended on the interaction of MM (MM0 vs. MM2) and Valence (positive, negative, neutral), $F(2, 44) = 6.89$, $MSE = 1.40$, $p = .002$, $\eta_p^2 = 0.24$. At baseline (CS selection phase) ratings did not differ between the sounds that were to be paired with positive ($M = 5.17$), negative ($M = 5.00$), or neutral ($M = 4.96$) words, $F(2, 44) < 1$. However the ratings of these sounds did differ on the measurements after the EC procedure, $F(2, 44) = 8.63$, $MSE = 2.60$, $p = .001$, $\eta_p^2 = 0.28$. Just as in Experiment 1, the sounds paired with the negative US words were rated more negatively after conditioning ($M = 3.70$) than the sounds paired with the neutral US words ($M = 4.91$), $t(22) = -2.421$, $p = .024$. Sounds paired with positive US words were rated marginally more positively than sounds paired with neutral words, $t(22) = -1.95$, $p = .064$.

Extinction

Figure 5.1 shows the subjective ratings of CS as a function of MM. An ANOVA of the ratings was performed with the factors Valence (positive, negative, neutral) and MM (MM2, MM3, MM4, MM5, and MM6). While there was an effect of valence, $F(2, 44) = 10.58$, $p < .001$, $\eta_p^2 = 0.33$, there was no main effect of MM, $F(4, 88) < 1$. For the interaction of MM and valence, Mauchly's test indicated that the assumption of sphericity had been violated $\chi^2(35) = 79.84$, $p < .001$. Therefore the degrees of freedom were corrected using the Greenhouse-Geisser procedure, $\epsilon = .44$. There was no interaction of MM and valence, $F_{GG}(8, 176) = 1.03$, $MSE = 2.03$, $p = .389$, $\eta_p^2 = 0.05$. This indicates that the EC effect did not change over time, which implies that no extinction occurred.

However, given the fact that null results do not allow strong conclusions, the rating pattern at the end of the extinction phase (MM6) was examined separately as a stricter test for resistance to extinction. This concerned the same contrast as used to test for the conditioning effect at MM2. At MM6 the sounds paired with the negative US words were not rated significantly more negative after conditioning ($M = 4.00$) than the sounds paired with the neutral US words ($M = 4.61$), $t(22) = -1.39$, $p = .179$, likewise sounds paired with positive words ($M = 5.13$), $t(22) = 1.78$, $p = .090$, were not rated significantly more positive than sounds paired with neutral words. Furthermore, the effect sizes (Cohen's d) for sounds paired with negative words (vs. neutral) decreased from $d = 0.82$ at MM2 to $d = 0.39$ at MM6, and for the positive (vs. neutral) from $d = 0.50$ at MM2 to $d = 0.39$ at MM6. However, there was still a difference between the sounds paired with negative words compared to sounds paired with positive words as indicated by the effect of US valence in the overall analysis at MM6, $F(2,44) = 4.19$, $MSE = 1.76$, $p = .022$, $\eta^2_p = 0.16$.

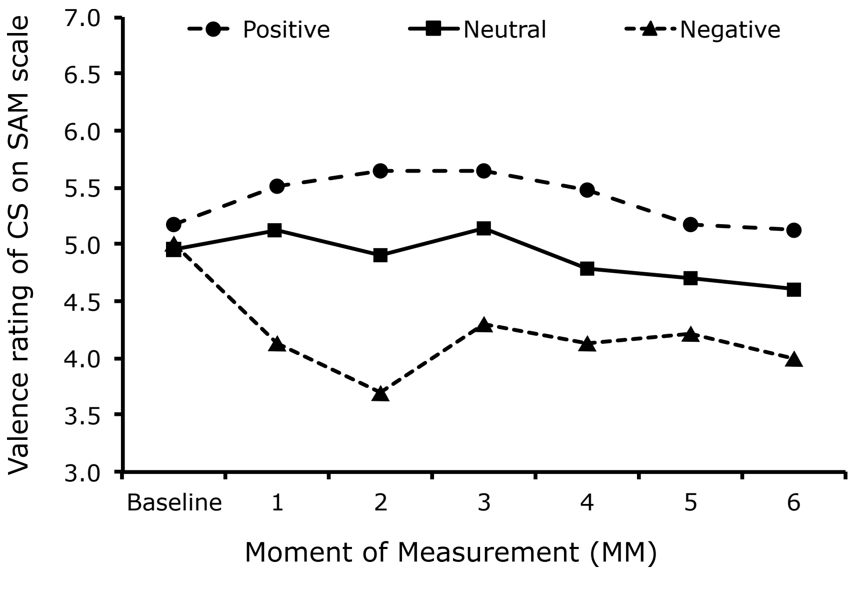

Figure 5.1: Mean of ratings on nine-point SAMv scale per moment of measurement for CS sounds that were paired with positive, negative or neutral US words at different Moments of Measurement (MM). MM 1 and 2 are after 10 and 20 CS-US parings, respectively. MM 3, 4, 5 and 6 are after 10, 20, 30 and 40 extinction trials, respectively.

Discussion Experiment 2

In Experiment 2 it was investigated to what extent the EC effect for environmental sounds was affected by an extinction procedure. To this end a conditioning procedure was followed by a substantial number of extinction trials, while repeatedly asking people to rate the affective valence of the sounds. Effects of conditioning were indeed found in the subjective ratings of the sounds paired with negative words and to a lesser extent in the subjective ratings of the sounds paired with positive words.

At first sight these effects did not change with repeated presentation of the sounds in the absence of the US, suggesting resistance to extinction. However, further analysis suggested that the EC effect as reflected in the subjective ratings were more apparent at the end of the conditioning period than at the end of the extinction period. This extinction effect is in line with the general pattern in previous EC studies. Hofmann et al. (2010) concluded that while the effects of EC are still present after extinction, the magnitude of the effect decreased from post acquisition to post extinction.

5.4 General discussion

To our knowledge the present study is the first to demonstrate changes in affective value of short environmental sounds through an EC procedure. The first experiment showed that EC effects were reflected in an explicit (subjective) as well as an implicit (RT and error rate) measure. The second experiment indicated that the acquired affective value, albeit weaker, remains present over a substantial number of repeated presentations of the conditioned stimulus alone.

The first experiment showed that the effects of the EC procedure evoked genuine changes in affective evaluation of environmental sounds. The changes in evaluation due to the conditioning procedure were reflected as an interference effect in the APT. Given that responses on the APT are low in controllability (De Houwer, 2003; Gawronski, 2009), it is unlikely that the effects of the EC procedure are attributable to demand effects (Hermans, Spruyt, & Eelen, 2003). Furthermore, the APT effects found for the conditioned sounds indicate that the acquired evaluation can behaviorally manifest itself in an automatic way (De Houwer et al., 2009). It has been argued that effects on implicit measures such as the APT mimic spontaneous behavior in real life (De Houwer, 2006; Fazio & Olson, 2003). Therefore, these findings suggest that learned evaluation of environmental sounds could influence spontaneous behavior in our daily lives.

The effects on the APT also demonstrate that the affective value can be changed through EC in negative as well as positive direction. That is, when used as primes in the APT, both sounds paired with positively valenced US words and sounds paired with negatively valenced US words during the conditioning phase caused shorter response times to targets with the same compared to opposite valence. However, the subjective ratings in the first study only reflected effects of conditioning for the sounds paired with negative words compared to sounds paired with neutral words, while ratings of sounds paired with positive words did not differ from the latter. This might suggest the presence of a negativity bias, the idea that negative events are more salient, powerful and have stronger effects compared to positive events (Kanouse & Hanson, 1972; Rozin & Royzman, 2001). Indeed several previous studies did find stronger EC effects on explicit ratings for stimuli paired with negative than for positive effects (e.g., in the gustatory domain; Baeyens, Eelen, Van den Bergh, & Crombez, 1990).

Differences between positive and negative conditioned stimuli might also arise when the degree to which the negative US are evaluated as negative is larger than the degree to which the positive US are evaluated as positive. In the present study positive and negative US were matched on affective extremity based on norms of a Flemish study (Hermans & De Houwer, 1994), which are likely to be applicable for Dutch participants. Future studies, however could include individual ratings of the US to control even more for affective extremity differences. Differences in individual US ratings may explain that, while the subjective conditioning effect for sounds paired with positive words was absent in the first experiment, there was a small effect in the second experiment.

The second experiment showed that effects of EC are still present after at least 40 CS presentations in absence of the US. However, the effects were less pronounced after the extinction phase compared to directly after conditioning. Given the prediction of resistance to extinction (Baeyens et al., 1992), the findings cannot be fully explained by the referential account of EC, which assumes that the EC effect occurs due to automatically formed CS-US associations. However, the data do also not fully reflect expectancy learning as in Pavlovian conditioning in which propositions are formed about CS-US contingencies (Lipp & Purkis, 2006). Lipp and Purkiss (2006) argued that CS evaluations show extinction but at a slower rate than measures of US expectancy ratings. Previous studies claiming resistance to extinction have been criticized because too few extinction trials were used to demonstrate extinction as reflected in subjective evaluation of the CS (Lipp & Purkis, 2006). However, in the present study, even after a substantial number (40) of extinction trials per CS, the effect still remained. Furthermore, it is unlikely that the EC effect in the final

CS ratings reflect an integration of information about both the acquisition and extinction phase as is the case when only post-experimental ratings are taken. In the current study, repeated measurements of CS evaluation were taken throughout acquisition and extinction phases. Repeated measurements throughout the experiment have been shown to reflect current valence ratings rather than ratings based on integration of information over the experiment (Lipp & Purkis, 2006).

The present pattern of results best fits a dual process account of EC, which suggests that EC effects can occur through both referential and propositional processes (De Houwer, 2007; De Houwer et al., 2005). If these processes do occur simultaneously then part of the EC effect will disappear during extinction due to changes in US expectancy, while the EC effect formed through associations by mere co-occurrence of CS and US during the acquisition phase will remain after extinction. The current paradigm using explicit valence assessment and including a measure of contingency awareness prior to the extinction procedure may have emphasized propositional information about the CS and US contingencies. To avoid these effects a follow-up study may intermix an EC and extinction procedure with APT trials, through which a more unobtrusive measurement of valence can be obtained.

Taken together, the results of our study demonstrate that through EC short environmental sounds can attain a negative or, to a lesser extent, a positive value. This effect is reflected in both implicit and explicit measures, and persists, although in decreased magnitude, after repeated presentation of the sound. These findings are best explained by a dual-processing account of EC in which associative as well as propositional processes underlie the EC effect.

Our demonstration of EC in the auditory domain may further advance research into affective sound processing. Studying the influence of affective valence on auditory processing is hampered by confounds due to differences in acoustical features inherent to positive, negative, and neutral sounds (Aeschlimann et al., 2008). In addition, the study of affective sound processing using event-related brain potentials would only be possible with short sounds, so that the relevant information becomes available with a more or less constant timing. This requirement is hard to meet with naturalistic affective sounds. As we have shown, EC makes it possible to change the valence of sounds. EC therefore enables studying short acoustically identical stimuli that have acquired different affective valence for different people, and facilitates an event-related potentials approach. From our finding of partial resistance to extinction it follows that this method can also be used if repeated presentation of CS sounds in absence of the US is required. Thus, the current study not only demonstrates that the EC effect generalizes to the auditory domain, it also paves the way to study affective environmental sound processing while effectively controlling acoustic properties.

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Appendices

Appendix 5.A: *Length, Mean and SD of SAMv Rating and Source of Sounds Used as CS and as Primes*

Application	Description	Length (ms)	SAMv *M*(*SD*)	Source
CS	basket ball bouncing	333	5.00 (0.93)	Gygi et al. (2007)
	Zipper	383	5.00 (0.85)	Gygi et al. (2007)
	computer sound	242	5.00 (1.36)	Fabiani et al. (1996)
	chicken cackling	375	4.93 (1.44)	Fabiani et al. (1996)
	mallard quacking	204	5.07 (2.05)	Fabiani et al. (1996)
	phone ringing	268	5.13 (1.30)	Gygi et al (2007)
	nose blowing	343	4.73 (1.71)	Fabiani et al. (1996)
	seal barking	400	5.27 (1.53)	Fabiani et al. (1996)
	wolf growling	391	4.73 (1.44)	Fabiani et al. (1996)
	raven cawing	215	4.73 (1.44)	Fabiani et al. (1996)
	car starting	216	4.67 (1.29)	Gygi et al (2007)
	pig grunting	215	5.40 (1.68)	Fabiani et al. (1996)
	owl calling	368	5.53 (1.81)	Fabiani et al. (1996)
	throat clearing	282	4.27 (1.16)	Fabiani et al. (1996)
	hand clap	317	4.20 (1.47)	Fabiani et al. (1996)
	sheep bleating	346	5.80 (1.97)	Fabiani et al. (1996)
	sneeze	333	4.20 (1.37)	Gygi et al (2007)
	water pouring	392	5.93 (1.16)	Gygi et al (2007)
Pre-rated	bird chirping	346	6.87 (1.85)	Bradley & Lang (2007)
	gun shot	343	2.87 (1.64)	Gygi et al (2007)
Practice	clock ticking	142	5.13 (1.25)	Gygi et al. (2007)
	drum roll	361	5.20 (1.61)	Fabiani et al. (1996)
	phone ringing (old)	415	5.33 (1.61)	Gygi et al. (2007)
	helicopter	297	5.53 (1.30)	Gygi et al. (2007)

Note: All sounds were rated previously in a separate sound rating study ($N = 15$, age: $18-30$, normal hearing, Dutch speaking) on a computer administered pictorial nine-point self assessment-manikin valence scale (SAMv; Bradley & Lang 1994) ranging from very upleasant (1) to very pleasant (9).

Appendix 5.B: *Valence Category Affect, Affect Extremity, Familiarity and Word Length of Words Used in the Evaluative Conditioning Phase.*

Set	Word (Original)	Word (English)	Valence	Affect	Familiarity	Affect Extremity	Word length (characters)
A	VREDE	Peace	Positive	6.47	4.91	2.47	5
	HEMEL	Heaven	Positive	5.61	4.73	1.61	5
	VLINDER	Butterfly	Positive	5.75	4.69	1.75	7
	BLOESEM	Blossom	Positive	5.84	4.14	1.84	7
	ZON	Sun	Positive	6.33	6.19	2.33	3
	VUILNIS	Garbage	Negative	2.34	4.88	1.66	7
	PANIEK	Panic	Negative	2.30	4.84	1.70	6
	PIJN	Pain	Negative	1.80	5.50	2.20	4
	DOOD	Death	Negative	1.94	4.63	2.06	4
	HAAT	Hatred	Negative	1.36	4.50	2.64	4
	PAPIER	Paper	Neutral	4.14	5.97	0.14	6
	DOOS	Box	Neutral	4.13	5.19	0.13	4
	STOEP	Sidewalk	Neutral	4.02	4.61	0.02	5
	LIJN	Line	Neutral	3.92	4.88	0.08	4
	TROMPET	Trumpet	Neutral	3.95	3.39	0.05	7
B	POESJE	Kitten	Positive	5.64	5.34	1.64	6
	CADEAU	Present	Positive	6.14	5.17	2.14	6
	BRUID	Bride	Positive	5.86	4.50	1.86	5
	LENTE	Spring	Positive	6.19	5.38	2.19	5
	KNUFFEL	Hug	Positive	6.38	5.52	2.38	7
	SCHULD	Guilt	Negative	2.19	4.72	1.81	6
	ANGST	Fear	Negative	2.14	5.41	1.86	5
	PUIST	Pimple	Negative	2.00	4.94	2.00	5
	RODDEL	Gossip	Negative	2.02	4.77	1.98	6
	KANKER	Cancer	Negative	1.36	4.45	2.64	6
	STREEP	Stripe	Neutral	4.00	5.03	0.00	6
	SCHAAR	Scissors	Neutral	3.89	5.27	0.11	6
	TAS	Bag	Neutral	4.08	5.14	0.08	3
	RAADSEL	Riddle	Neutral	4.14	4.52	0.14	7
	ACCENT	Accent	Neutral	4.00	4.53	0.00	6

Appendix 5.C: *Valence Category Affect, Affect Extremity, Familiarity and Word Length of Words Used as Targets in the affective priming task.*

Word (Original)	Word (English)	Valence	Affect	Familiarity	Affect Extremity	Word length (characters)
Gezond	Healthy	Positive	6.33	6.48	2.33	6
Betrouwbaar	Trustworthy	Positive	6.33	6.26	2.33	11
Oprecht	Sincere	Positive	6.17	5.62	2.17	7
Sympathiek	Sympathetic	Positive	6.14	6.22	2.14	10
Aangenaam	Pleasant	Positive	6.07	6.16	2.07	9
Origineel	Original	Positive	5.98	6.31	1.98	9
Creatief	Creative	Positive	5.91	5.85	1.91	8
Moedig	Courageous	Positive	5.90	6.01	1.90	6
Behulpzaam	Helpful	Positive	5.98	5.96	1.98	10
Zuiver	Pure	Positive	5.75	5.75	1.75	6
Wijs	Wise	Positive	5.68	5.54	1.68	4
Vlot	Fluent	Positive	5.59	6.07	1.59	4
Brutaal	Bold	Negative	1.75	5.88	2.25	7
Leugenaar	Liar	Negative	1.56	6.17	2.44	9
Vijandig	Hostile	Negative	1.80	5.63	2.20	8
Egoïstisch	Selfish	Negative	1.79	5.83	2.21	10
Agressief	Aggressive	Negative	1.89	6.14	2.11	9
Irriterend	Irritating	Negative	1.99	5.20	2.01	10
Vervelend	Annoying	Negative	2.09	6.25	1.91	9
Jaloers	Jealous	Negative	2.17	6.17	1.83	7
Depressief	Depressive	Negative	2.25	6.20	1.75	10
Lastig	Difficult	Negative	2.27	6.15	1.73	6
Dom	Dumb	Negative	2.34	6.09	1.66	3
Kwaad	Angry	Negative	2.35	6.40	1.65	5

6

Summary and Discussion

Perception is often understood as a direct and true reflection of our outer world. The plausibility of this view, however, has been challenged on various grounds. Information we receive through our senses is often incomplete or ambiguous and therefore needs to be combined with other available information to form a percept (e.g., Bruner & Goodman, 1947; Kersten & Yuille, 2003; McClelland et al., 2014). In addition, neurostructural and neurophysiological findings as well as recent predictive coding models of brain function are in agreement with the notion that information (e.g., perceptual, cognitive and affective information) is integrated at all levels of processing, including perceptual levels (e.g., see Angelucci et al., 2002; Markov & Kennedy, 2013; Ninomiya et al., 2012 [neurostructural]; Gilbert & Li, 2013; Rauss et al., 2011 [neurophysiological]; Clark, 2013; Lupyan, 2015a [predictive coding]). It has been argued that affect is an important and pervasive source of information, which changes how the brain processes incoming sensory information and informs conscious perception (e.g., E. Anderson et al., 2011; Asutay & Västfjäll, 2012; Barrett, 2017b; Barrett & Bar, 2009; Barrett & Bliss-Moreau, 2009; Meier et al., 2007; O'Callaghan et al., 2017; E. H. Siegel & Stefanucci, 2011; E. H. Siegel et al., 2018; Stefanucci et al., 2011; Stefanucci & Storbeck, 2009).

Several studies have investigated the idea that affect impacts basic perception in the visual domain, but only a few looked at affective influences on basic auditory perception (Asutay & Västfjäll, 2012; E. H. Siegel & Stefanucci, 2011;

Weisz et al., 2007). Previous research did show clear dependencies between affective state, affective quality, and affect disposition on the one hand and annoyance responses towards sounds on the other hand (Bartels et al., 2015; Crichton et al., 2015; Job, 1988; van Kamp et al., 2004; Miedema & Vos, 2003; Västfjäll, 2002; Västfjäll et al., 2003). These findings clearly demonstrate that affect can influence the way in which we experience sound. However, an annoyance response encompasses much more than auditory perception alone (e.g., it has a strong evaluative component to it as well). Therefore, inspired by these findings and by indications that affect impacts basic perception, we set out to explore affective influences on more basic aspects of sound experience.

The central issue of this thesis thus concerned the extent to which relatively basic auditory perception and processes are associated with affective states and traits. More specifically, it examined affective influences on pitch shift perception and masked auditory sensitivity. In our research we took efforts to avoid pitfalls common in studies about top-down effects on perception (see the Introduction chapter for a review of these pitfalls). The first section of the current chapter will provide an overview of the findings and conclusions of each of the four empirical chapters of this thesis. The second section will discuss general implications and limitations of our findings, thereby taking into account some of the pitfalls, and provide suggestions for future research. The last section of this chapter will provide an overall summary and conclusion of this thesis.

6.1 Overview of Empirical Findings

This thesis contained four empirical chapters. The current section will summarize each of these chapters.

Chapter 2: Effects of Mood on Pitch Shift Perception

To examine affective influences on auditory perception, in Chapter 2 we compared pitch shift perception between participants in a happy mood and a sad mood. We used tone pairs with an ambiguous pitch shift direction. That is, the pitch could be heard as going upward or downward in pitch from the first to the second tone depending on which of two pitch cues the participants used. We found a small, but significant, effect of mood on pitch shift judgment: Listeners in a sad mood judged tone pairs with ambiguous pitch shifts more often as downwards than happy listeners. This effect was not conditional on the response labels ("UP" or "DOWN") of the buttons that the participants used to indicate pitch shift direction, which suggests that it was a genuine effect on pitch shift judgment and could not be attributed to response selection bias caused by an affective mapping effect (see Eder & Rothermund, 2008; Lavender & Hommel, 2007). The findings of Chapter 2 thus suggest that auditory perceptual judgment can be subject to affective influences, which is consistent with the idea that affect pervades our experience of the auditory world.

The findings are in line with several theories, such as the affect-as-information account of mood congruent judgments (Schwarz & Clore, 2007, 1983), or the notion that affective feelings activate conceptual metaphors that bias perception (Crawford, 2009; Meier & Robinson, 2004; Weger et al., 2007). Furthermore, we suggested that biased competition mechanisms (Desimone & Duncan, 1995) in the brain may have enhanced perception of the mood congruent pitch shift. However, the findings of Chapter 2 cannot answer the question at what level of processing biasing takes place and whether perception proper and/or perceptual judgment (assuming these can be separated) are affected by mood. Specifically, the possibility cannot be excluded that participants (consciously or unconsciously) adopted a more lenient criterion for judging pitch shift as upwards than as downwards in a happy state compared to a sad state or vice versa. In Chapter 3 and 4 we therefore did not attempt to measure perceptual bias but used a performance-based task measuring auditory sensitivity to minimize possible contamination by changes in the decision criterion.

Chapter 3: Inconsistent Effects of Mood on Sensitivity to Masked Sounds

In Chapter 3 we explored affective influences on auditory perception by comparing the masked auditory threshold, which is a measure of auditory sensitivity, between listeners in an anxious, sad, happy, or calm mood. This allowed us to disentangle possible effects of pleasure from effects of arousal on the masked auditory threshold and to check for interaction effects between these two dimensions of affect. Furthermore, we employed a 2IFC task to measure the masked auditory threshold, which yields a relatively unbiased measure of sensitivity in noise.

We investigated the effect of the pleasure and arousal dimension of mood on the masked auditory threshold in two experiments. In Experiment 1 the mood induction procedure was accompanied by affective music, while in Experiment 2 the mood induction procedure was accompanied by affective pictures. In Experiment 1 listeners in low arousal (calm and sad) moods had on average a lower masked auditory threshold, thus higher sensitivity, than listeners in a high arousal (happy and anxious) mood. Additional (polynomial regression) analysis suggested a curvilinear relation between subjectively experienced arousal and threshold, which reflected that listeners who reported very low subjective arousal or very high subjective arousal had higher thresholds (lower masked sensitivity) than listeners with a more intermediate (optimal) level. The presence of a curvilinear relationship is in line with theories about the relation between arousal and performance in general (Aston-Jones & Cohen, 2005; Easterbrook, 1959; Kahneman, 1973).

However, despite successful mood induction, arousal did not have the same effect in Experiment 2. In Experiment 2, the effect of arousal on the masked auditory threshold did not reach significance but in fact showed a trend in the opposite direction to the effect of Experiment 1. The inconsistent findings of the two experiments could not be explained by a curvilinear relation between subjective arousal and threshold across the two experiments. These results thus indicate that the effect of arousal on auditory masked sensitivity may depend on the modality of the mood inducing stimuli. We can only speculate about the exact cause of this dependency. We carefully matched sound level of the musical pieces used for the mood induction across mood conditions. It is thus unlikely that differences in sound level have caused differences in the threshold between low and high arousal conditions in Experiment 1. However, it was not possible to control for all other acoustic properties of the music, such as tempo, mode (minor, major) and other spectral properties because these properties are essential for giving the music its affective quality. Therefore, these acoustic differences, which were not an issue in Experiment 2, may have driven the effects in Experiment 1 (and not Experiment 2). To the best of our knowledge, such effects of music on the threshold have not been reported in the literature before. It may be of interest to explore such effects in future research. Furthermore, in addition to the difference in possible impact of acoustic properties, there were other differences between the experiments. The effect of the mood induction on subjective arousal tended to be more extreme in the pleasant conditions elicited by the music-based than by picture-based induction, which may have contributed to the discrepancy in findings between the two experiments. Also, more complex interactions between modality of mood-induction and elicited mood may have occurred. For example, attention may have been more focused on the auditory domain after music-based than picture-based mood induction, which may have had different consequences for the effects of arousal in each experiment.

The discussion of Chapter 3 provided several suggestions for further research into the dependencies between affective state and auditory sensitivity, some of which will be discussed below. In Chapter 4 we also further investigated the relationship between auditory sensitivity and affect. However, in contrast to Chapter 3, we looked at affect as disposition (trait) rather than state, because it has long been suggested that there is a link between perceptual sensitivity and dispositions such as affective reactivity to stimuli.

Chapter 4: The Relationship Between Trait Reactivity and Perceptual Sensitivity

In Chapter 4 we examined the relation between (auditory and general) sensitivity to weak stimuli and self-reported reactivity to strong stimuli. Several theorists have suggested that sensitivity and reactivity are two sides of the same coin (Aron & Aron, 1997; Eysenck, 1967; Nebylitsyn et al., 1960), while others argue that they are independent characteristics (Ellermeier et al., 2001; Evans & Rothbart, 2008). As we reviewed in Chapter 4, previous studies yielded inconsistent results regarding this matter. Those studies only considered reactivity in terms of the individual tendency to experience unpleasant affect (punishment reactivity) resulting from strong sensory stimulation. In our study we also took into account the individual tendency to experience pleasant affect (reward reactivity) resulting from strong sensory stimulation. We included this additional measure of reactivity based on predictions following from the neurobehavioral framework of the Predictive and Reactive Control Systems (PARCS) theory (Tops et al., 2010, 2014).

We found that self-reported as well as objectively assessed sensitivity to weak stimuli was associated with self-reported punishment and reward reactivity to strong stimuli. Importantly, however, these relationships only became apparent when the reactivity measures were controlled for each other, indicating a mutual suppression effect. The fact that previous studies did not take this suppression effect into account may explain the inconsistent results of these studies.

The findings of Chapter 4 thus suggest that sensitivity to weak stimuli and reactivity to strong stimuli are related tendencies, but this relationship may be obscured if punishment and reward reactivity are not both taken into account, which is in line with PARCS theory. Auditory sensitivity in noise thus seems associated with affect dispositions, specifically those concerning reactivity to strong environmental stimuli. Another relevant type of affect that may in part determine the auditory perception of environmental stimuli is the affective quality of those stimuli themselves. In the Chapter 5 we examined a method that could aid in studying how basic processing of auditory stimuli is influenced by their affective quality.

Chapter 5. Evaluative Conditioning as Method to Avoid Confounding by Low-Level Perceptual Feature Differences

In Chapter 5 we examined whether evaluative conditioning (EC) could be used to create changes in the affective quality of short environmental sounds. Through EC a stimulus can acquire positive or negative affective value by pairing it with another positive or negative stimulus respectively (De Houwer et al., 2001; Hofmann et al., 2010; Levey & Martin, 1975). EC effects have been demonstrated for various types of stimuli under various conditions but have been hardly studied in the auditory domain. Therefore we examined whether EC effects and its properties are generalizable to the auditory domain. This also allowed us to assess whether EC could be helpful in studying effects of affective quality on basic sound perception. Differences in affective quality of environmental sounds (e.g., the sound of a baby crying or a bird singing) is frequently accompanied by differences in low-level features of these sounds (e.g., frequency components and amplitude), which may confound effects of affective quality on basic auditory perception. Evaluative conditioning may allow manipulation of the affective quality of a stimulus, while its physical properties remain the same. EC as a tool to study processing of affective environmental sounds should enable changes in valence in both negative and positive directions. Furthermore, these changes in affective quality should be genuine and not attributable to demand effects, and, to make it suitable for psychophysical and psychophysiological studies, applicable to short sounds and lasting over repeated presentation of these sounds in the absence of unconditioned stimuli. These properties were investigated in two studies.

In Experiment 1, neutrally evaluated short (< 400 ms) environmental sounds were repeatedly paired with positive, negative, or neutral words during an evaluative conditioning phase. Next, affective quality of the sounds was assessed by means of direct subjective ratings as well as by an affective priming task. The latter is an indirect measure of affective quality of which the outcome is relatively difficult to voluntary control for participants. We found affective priming effects on this task for sounds with a pre-existing positive or negative affective quality. This showed that the affective priming task, which was originally designed for visual stimuli, indeed reflected affective evaluation of short affective sounds. The results regarding the affective quality of the conditioned sounds were as follows: Affective priming effects in the expected direction were found for sounds that had been paired with positive or with negative unconditioned stimuli. The sounds had thus acquired the expected affective quality through EC and this quality was relatively automatically reflected in behavior. The subjective ratings reflected the EC effect only for sounds paired with negative words. Experiment 1 thus demonstrated that EC brought about genuine changes in affective quality in the negative direction, and to a lesser degree in the positive direction.

In Experiment 2, we investigated to what extent the EC effect for environmental sounds was a lasting effect. In this experiment an evaluative conditioning phase was followed by a substantial number (40) of extinction trials in which the conditioned sounds were presented in absence of the unconditioned stimuli while repeatedly asking people to rate the affective valence of the sounds. The results of this experiment largely replicated the EC effects on subjective ratings found in Experiment 1 but in this case the pairing with positive unconditioned stimuli also yielded a near significant EC effect. Furthermore, the second experiment indicated that the acquired affective quality remained present over a substantial number of extinction trials. The sizes of the EC effects were however numerically smaller at the end of the extinction phase than directly after the EC phase. Those findings suggests that EC as a method is suitable for applying enduring affective changes and can be used for psychophysical and psychophysiological studies, which require repeated presentation of (conditioned) sounds in absence of the unconditioned stimuli. However, since the effects were less pronounced after the extinction phase, compared to directly after conditioning, it may be advisable to add reconditioning phases after repeated conditioned stimuli-only presentations.

Taken together, EC induced genuine and lasting changes in affective quality of short environmental sounds in negative and, albeit subjectively to a lesser extent, positive direction. These findings show the potential of employing EC as a method to avoid confounding by low level sound features when studying auditory processing and perception of affective sounds: It enables employment of short acoustically identical stimuli that have acquired different affective valence for different individuals.

A point of concern for the use of EC may be that findings regarding processing of sounds with acquired valence do not apply to other affective sounds. Some researchers argue that biologically relevant stimuli, such as snakes and spiders, are processed more efficiently than stimuli that have acquired their emotional value through learning, such as knives and guns (Öhman & Mineka, 2001). This point should not discourage one to use EC. In fact EC will allow comparing auditory processing of biological and learned affective sounds. Furthermore, many stimuli we encounter have acquired their emotional value over life (Juslin & Västfjäll, 2008; Rozin & Millman, 1987). A full understanding of emotional sound processing is thus best served by also studying stimuli with acquired valence. EC is thus a valuable tool in the study of affective sounds processing.

6.2 Taking Stock and Moving Forward (II)

Now that the empirical findings of this thesis have been summarized in the previous section, the current section will evaluate these findings in the light of the penetrability debate. Furthermore, the current section will assess what may be inferred from these findings regarding our responses to the day-to-day auditory environment. This section will also address several important limitations of the studies presented in this thesis and explore how we can move forward from here to learn more about the integration between auditory perception and affect.

Implications for the penetrability debate

As discussed in the Introduction chapter of this thesis there has been a long-standing debate about the degree to which perception can be modulated by cognition or affect. This so-called penetrability debate formed an important background for understanding the theoretical relevance of our overall research question. The current thesis cannot, and also did not aim to, provide a final answer to this debate, which may be unsurprising given the fact that the debate has been running for over more than a century. The discussion below will however provide some reflection on how the findings of this thesis may (and may not) contribute to the penetrability debate. Please refer to the Introduction chapter for a discussion about the difficulty to define what the concepts of "penetrability", "affect" and "auditory perception" exactly entail. The following sections will evaluate our findings against specific requirements for penetrability that have been set by some authors (Firestone & Scholl, 2016; Pylyshyn, 1999) and will delineate between "perceptual" and "decision" processes based on the framework of signal detection theory (Green & Swets, 1966).

Alternative explanations

In order to demonstrate that affect penetrates perception one should be able to exclude possible alternative explanations for effects of affect on measurements of perception. First, the affect manipulation should only create the intended affective differences between conditions, and not other differences that may impact auditory processing, such as acoustic auditory feature differences. This point has already been discussed above in the overview of Chapter 3 and 5. Second, differences in outcomes of perceptual tasks between affect conditions should reflect differences in perceptual and not in non-perceptual processes. In fact, most of the pitfalls mentioned by Firestone and Scholl (2016, particularly #2, #4, #5 and #6, see Introduction chapter) refer to this latter requirement. However, as argued in the Introduction chapter, certain attention and memory processes in fact seem to be integral to perceptual processing, and may be exempt from this requirement. In order to demonstrate affective penetrability of (early) perceptual processing, one should thus rule out that affect modulated judgment (pitfall #2) or response (pitfall #3) instead of perceptual processes. As expounded in the Introduction chapter, we took several measures to abate the influence of task demand and response bias on the results. These measures make it unlikely that the effects found can be attributed to these factors. Effects on judgment as alternative explanation for affective modulation of perception, however, could not be ruled out in all chapters. In Chapter 2 we explicitly attempted to measure bias in perceptual experience using an appearance-based measure. Both decisional and perceptual biases would be reflected in the outcome of this measure (see Introduction chapter and further below for explanations). Therefore, as mentioned, we could not exclude the possibility that the biasing effect we found of mood on pitch shift judgment was an effect on judgment rather than on perceptual processes. By contrast, in Chapter 3 and 4 we measured auditory sensitivity using a task that minimized contribution of judgment bias and the task outcome thus more likely reflected perceptual processes only. In Chapter 3, however, affective state did not unequivocally cause changes in auditory sensitivity. In Chapter 4 we did find a relation between affective disposition towards strong environmental stimuli and auditory sensitivity. However, the study design of Chapter 4 was correlational and therefore the findings of this study do not allow conclusive statements about the causal nature of the relationship between affect disposition and auditory sensitivity. In fact, based on PARCS theory and previous studies we hypothesized that both outcomes may be (partly) driven by activity of the salience network, which does not seem to suggest a direct effect of affect on early perception.

Together the findings presented in these three chapters do not provide sufficient basis to conclude (nor refute) that affect penetrated early auditory processing in a strict sense. This is not to say that our findings are not meaningful or do not provide any contribution to the penetrability debate. The summary below will elaborate further on this point, but first the discussion will focus on another aspect of penetrability: semantic relatedness.

Semantic relatedness

Some definitions of penetrability entail that perception is only truly penetrated by affective or cognitive states when there is a semantically coherent relation between the content of these states and the content of the penetrated perceptual process (e.g., Pylyshyn, 1999). This criterion for penetrability has also been referred to as the semantic criterion (e.g., Cecchi, 2014; Stokes, 2013). One could argue that such a meaningful, or semantically coherent, relationship between the penetrating state and perception was present in the studies presented in Chapter 2. We theorized that the affective meaning of one's current state (i.e., positive or negative) shaped the content of the perceptual judgment (i.e., up or down pitch shift) in a meaningful (i.e., positive = up; negative = down) way. Such meaningful relationship however was less clearly present in Chapter 3 and 4. The aim of the studies in these chapters was to examine to what extent auditory sensitivity in general was associated with affective state or trait. Such an effect may be considered similar to a change in heart rate due to a belief that there is danger looming, which can be explained purely in biological or physical terms, and thus is not a case of cognitive or affective penetration (Pylyshyn, 1984; see Cecchi, 2014). We did not examine to what extent sensitivity to specific stimuli or features, and thereby the content of perception, was meaningfully related to the content of the affective state. That is, we did not use different stimuli to examine differential effects on sensitivity depending on the affective meaning of the state. So even if in Chapter 3 we had found unequivocal changes in auditory sensitivity due to changes in mood, according to some definitions of penetrability, this would not have demonstrated cognitive penetrability of auditory processing by affect. Thus, while the sensitivity measure in Chapter 3 and 4 offered a more "pure" measure of perception, this came at the expense of being able to measure bias in perceptual content.

Summary

Given the inconclusiveness regarding the (perceptual or decisional) locus of the effects found and the fact that there was no semantic relatedness between affect and perception in all chapters, the findings of the presented chapters do not yet permit firm conclusions regarding affective penetration of early audition. However, we did find that basic auditory perceptual judgments were dependent on affective state in a meaningful way (Chapter 2). This does suggest that auditory perceptual experience is at least to some degree penetrable by affect. This is not a trivial notion, because affective penetration of perceptual experience may have consequences for how we further appraise and respond to the stimuli in our environment and thus for our daily interaction with the world. The next section will elaborate on this point. The subsequent section, on limitations and suggestions for further research, will describe some ideas for studies that may allow more conclusive statements about affective penetrability of early auditory processing.

Implications for understanding responses to environmental sounds

Implicit in the reasoning towards formulation of the research question has been the belief that if affect were to influence basic auditory processing and perception, this would establish the pervasiveness of affect in auditory processing. This, in turn, would make a stronger case for taking affective influences seriously when studying determinants of day-to-day responses to sounds, including reactivity or annoyance. In other words, if affect influences basic perceptual processes such as those underlying pitch shift perception and sensitivity to sounds, it will likely also influence higher-level affective responses and cognitive beliefs regarding sound. At the time the research questions were formulated there was some evidence that brief affective states modulated early auditory brain potentials (Al-Abduljawad et al., 2008; Baas et al., 2006), and a limited number of behavioral studies had suggested that affect impacted visual perception (Bocanegra & Zeelenberg, 2009; Phelps et al., 2006). Given that we found some tentative indication that basic auditory perception is affectively informed, our findings fit within this body of research. For a full understanding of auditory perception, it thus seems noteworthy to take affective influences into account. Future studies may examine directly whether affect-induced changes in basic perception mediate changes in annoyance responses or attitudes towards sounds or other environmental stimuli.

The findings of Chapter 4 have additional implications for our understanding of noise annoyance or annoyance produced by other day-to-day environmental nuisances. In particular, the findings have implications for examining the temperamental and psychophysical determinants of annoyance. In Chapter 4 we found that reward reactivity suppressed the relation between (auditory and general perceptual) sensitivity and punishment reactivity. Reward reactivity will thus likely also suppress any association between perceptual sensitivity and noise sensitivity, which can be understood as a measure of punishment reactivity in the auditory domain and which is an important predictor of noise annoyance. This could lead to the conclusion that perceptual sensitivity is a negligible factor in explaining noise sensitivity or annoyance. However, based on the findings of our study we would expect that there is a relation between perceptual sensitivity and noise sensitivity, but this may only be revealed when reward reactivity is controlled for. Therefore, it is advisable to include measures of reward reactivity to strong stimuli in future studies and to control for it in order to gain a more complete picture of the determinants of noise annoyance. This is likely also the case for understanding other types of annoyance.

Finally, based on the findings of Chapter 2 it can be speculated that affective biases towards specific features of environmental stimuli contribute to the perpetuation of affective states and perhaps even symptoms of affective disorders. The argument here is as follows: If perceptual judgment is biased by current mood, and perception is taken by the individual to reflect reality, mood biased perception thereby justifies and perpetuates the individual's current mood. This is similar to the notion that the recall of mood-congruent memories facilitated by one's current mood will strengthen and prolong this mood (Bower, 1981). It also fits with findings of mood-congruent attention biases found in individuals with affective disorders (García-Blanco, Perea, & Livianos, 2013; Koster, De Raedt, Goeleven, Franck, & Crombez, 2005; F. C. Murphy et al., 1999) and the idea that such biases play an important role in the etiology and maintenance of mood disorders (Beevers & Carver, 2003). In fact, mood biases in basic perception may be particularly persistent. Why would this be the case? For one thing, in daily life, perceptual experiences are ordinarily taken to provide true knowledge of the outer world and are used to justify our beliefs about it (e.g., S. Siegel & Silins, 2014). For another, it may be difficult to become aware of such biases because they do not concern obvious or explicitly affective content. It thus seems a worthwhile endeavor to explore whether biasing effects of mood on pitch shift perception extend to more chronic affective states as found in mood-disorders and the possible role of such biases in the maintenance of these states.

Limitations and Suggestions for Further Research

Various limitations to our studies and suggestions for further research have been provided within the chapters concerned and earlier in this discussion. This section will elaborate further on some of these limitations and suggestions and where possible integrate them across chapters.

Separating bias and sensitivity

As mentioned, the effect of mood on pitch shift judgment found in Chapter 2 may be explained by an increase in sensitivity to mood congruent cues (i.e., up-going pitch shift in happy mood), by a lowered criterion for identifying mood congruent cues, or by a combination of both. Similarly, as discussed before (see Introduction chapter and Chapter 3), previous findings of increased perceived loudness in high arousal negative mood (E. H. Siegel & Stefanucci, 2011) may also be explained as increased auditory sensitivity and/or as biased judgment. It thus seems warranted to explicitly investigate the relative contributions of bias and sensitivity to mood modulation of auditory perception. The designs used in Chapter 2 and also in the other chapters did not allow for investigating this. In Chapter 3 and 4 we opted for a 2IFC adaptive method, instead of a signal detection task that allows calculation of bias and sensitivity. As explained in the Introduction chapter the reason for this choice was that task efficiency was an important consideration given the likely fleeting nature of induced moods. At the time we designed the experiments, there were no efficient (i.e., adaptive) testing methods available that yielded estimates of both sensitivity and the criterion. However, recently new methods have been developed based on signal detection theory and Bayesian adaptive inference that do exactly this (Lesmes et al., 2015). Using these new methods for investigating effects of mood on perception provides a promising avenue for further research.

A word of caution is in place here in case one aims to apply signal detection measures (adaptive or non-adaptive) to establish perceptual bias. In order to study biasing effects of mood, or other conditions, on perception of particular stimuli or features, it seems suitable to employ a discrimination task and compare the outcome on this task between conditions. A discrimination task requires participants to decide on each trial which of two different signals was presented (e.g., whether a tone pair with up-going pitch shift or a tone pair with down-going pitch shift was presented). Note that this task is different from a detection task where participants decide whether a signal was present or not. If a discrimination task is used, it is important to realize that it is ill suited to look at differences in sensitivity (d') between conditions to determine if there was a bias in perception or not (Witt et al., 2015). A bias in perception will not show up in the sensitivity measure but in the criterion calculated from these tasks. However, one can also not simply interpret a shift in the criterion as measure of perceptual bias because it can be confounded by decision or response bias. One solution to this problem is to use a detection task instead of a discrimination task. If a detection task is used, perceptual biases will be reflected in the sensitivity measure (e.g., higher detection sensitivity for up-going tones in positive compared to negative mood) and the criterion will reflect only decisional processes.[1]

It should be noted, however, that effects on perception of near threshold stimuli typically used in detection tasks do not necessarily translate to supra threshold levels because different processes may be at work (Dalton, 1996). Therefore, it is important to use evidence obtained by a variety of other techniques. This points aligns with a general recommendation that should be followed to answer the question to what extent affect influences auditory perception and/or judgment: Various methods should be used and it should be examined to what extent outcomes of these methods converge (see also, Philbeck & Witt, 2015). For example, as discussed in the Introduction chapter, a promising approach is to use behavioral and psychological measures in combination with neuroimaging and electrophysiology techniques. The latter allow measurement of the location and timing of the effects in the brain, and the former provide interpretations of these effects. In the case of pitch shift direction, first more should be learned about the process that transforms stimulus information to the decision outcomes, such as which auditory-driven responses are used as evidence to form the pitch shift decisions (see Tsunada et al., 2016). While in recent years some progress has been made in understanding how and where in the brain sensory inputs are translated into perceptual decisions, this is still a matter of ongoing research (Tsunada et al. 2016).

[1] This is an important issue because, as Witt et al. (2015) argue, several researchers using a discrimination task appear to have erroneously concluded that effects of a manipulation were not perceptual but due to response bias. These researchers arrived to this conclusion because they only found effects of a manipulation on the criterion and not on the sensitivity measure derived from a discrimination task. As mentioned in the text, this conclusion is erroneous because when a discrimination task is used a bias in perception will in fact generally show up as an effect on the criterion and not on the sensitivity measure. The perceptual bias does not show up in the sensitivity measure because the manipulation does not only shift the probability distribution (see Introduction chapter) of one of the signals but of both of the signals. In other words, the distance between the distributions, and thus the sensitivity measure, remains the same regardless of the manipulation. Instead, the shift in the two distributions will show up as a change in the criterion. However, an effect on the criterion does not guarantee that there is a perceptual bias, because the criterion reflects both perceptual and response bias. So, in the context of discrimination tasks, perceptual bias and response bias cannot be discerned. If instead of a discrimination task a detection task is used, the manipulation will only shift the S (signal) and not the SN (signal+noise) distributions and therefore perceptual biases will be reflected in the sensitivity measure and the criterion will reflect only decisional processes. For more information, examples and graphical explanations regarding this issue see Witt et al. (2015)

Semantic relation between affect and perception

As discussed above, the type of affective influence that Chapter 3 and 4 aimed to measure did not follow the semantic relatedness criterion used in some definitions of penetrability. The aim of the studies in these chapters was to examine to what extent auditory sensitivity in general was associated with affect. Future studies are needed to elucidate to what degree affect, depending on relatedness in affective meaning, selectively influences sensitivity to specific stimuli or features. To this end, the methods of Chapter 3 (with the improved adaptive methods discussed above) and Chapter 5 may be combined. In Chapter 5 we showed that EC induces long lasting changes in affective quality of short sounds. By using positively and negatively conditioned sounds as targets in (separate) adaptive masked threshold tasks, it can be investigated to what extent effects of mood on auditory sensitivity depend on the affective quality of the sound. Furthermore, a meaningful connection between the affective state and the stimuli used for the perceptual task may also elicit more clear effects of affect on perception than those found in Chapter 3, which focused on perception of a 1 kHz tone that had no clear affective connotation.

Mechanisms

Each of the first three empirical chapters have provided suggestions for plausible neural mechanisms that may underlie affective modulation of auditory perception. So far, however, we have not tested these mechanisms explicitly. Further research should be designed to specifically test which of these mechanisms indeed mediate affective modulation of auditory perception. The following discussion briefly describes the three main mechanisms we have proposed in the empirical chapters and how these mechanisms may be tested. In Chapter 2 we suggested that biased competition mechanisms may explain mood biases in perception. One of the ways to test plausibility of this mechanism is to use neural network modeling techniques to verify if psychophysical findings, and, if available, neuroimaging findings of mood biased pitch shift perception can be explained by biased competition (for a neural network modeling study of pitch shift bias by auditory context, see Huang, Englitz, Shamma, & Rinzel, 2015). Furthermore, in Chapter 3, we suggested that changes in tonic NE activity of the LC may mediate effects of arousal on auditory sensitivity. Indeed, animal studies provide some support for the hypothesis that tonic NE modulates sensory coding in the brain and it has been suggested that NE plays a role in adaptation of perceptual processing to the demands of the current context. However a causal link between NE modulation of sensory neurons and perceptual changes has not been clearly established (Devilbiss, 2019). As we have suggested in the discussion of Chapter 3, parametric manipulations of arousal are needed to further investigate the possibly curve-linear relationship between arousal and auditory perceptual sensitivity. This should be combined with monitoring NE activity, for example by the use of pupil dilation as an index of NE[2] (Aston-Jones & Cohen, 2005; P. R. Murphy, Robertson, Balsters, & O'Connell, 2011; Nieuwenhuis, De Geus, & Aston-Jones, 2011), in order to analyze to what extent this index of NE mediates the influence of affective arousal on perception (see Jepma & Nieuwenhuis, 2011 [pupil size and decision making in humans]; McGinley et al., 2015 [pupil size and auditory perception in mice]). Finally, in Chapter 4 we proposed that individual differences in the tendency to engage the salience network may explain the relationships we found between reactivity measures and perceptual sensitivity. This can be investigated in a neuroimaging study that examines how reactivity and sensitivity traits relate to functional connectivity of the salience network in rest (see e.g., Markett et al., 2013; Seeley et al., 2007) and, possibly, also during task performance (see e.g., van Tol et al., 2013).

Generalizability

A final limitation of our studies is that most of the participants involved were young-adult females. Our findings should not be too hastily generalized to males and older individuals. Some differences between men and women in terms of pitch perception discrimination abilities and auditory sensitivity have been found (Rammsayer & Troche, 2012). Age has also been associated with hearing sensitivity (D. Robinson, 1988). Whether sex and age interact with effects of emotion on these auditory abilities is a question to be further investigated.

6.3 Conclusion

The studies described in this thesis contributed towards answering the question to what extent basic auditory perception and processing is associated with affect. Based on the results from these studies the following brief answer can be provided. Overall, we found some evidence for involvement of affect

[2]It should be noted however, that while pupil size is closely coupled to NE activity, it may also reflect activity of other neuromodulators (for recent discussions, see McGinley, David, & McCormick, 2015; Totah, Logothetis, & Eschenko, 2019).

in auditory perception, although the effects and relations were subtle. We found a small, but significant effect of mood on pitch shift judgment. Pitch shift direction was more frequently judged upwards by individuals in a happy mood compared to individuals in a sad mood. We also studied the effects of mood on auditory sensitivity. The effects of the arousal dimension of mood on sensitivity to sound in noise were inconclusive and seemed conditional on the mood induction modality. No effects of the pleasure dimension of mood on auditory sensitivity were found. However, we found that auditory sensitivity as well as general perceptual sensitivity were associated with affect disposition, specifically, affective reactivity towards strong stimuli. Notably, this association was only revealed when both approach reactivity and avoidance reactivity were taken into account. Finally, our last study showed that evaluative conditioning, used as a method to create affective quality in sounds, offers promising prospects to study auditory processing of affective sounds, because it allows avoiding the pitfall of confounding by low-level stimulus features.

Although our findings indicate that seemingly straightforward auditorily determined responses such as pitch shift perception and detection of sound in noise are associated with affective state or trait, more research is still needed to draw definitive conclusions regarding penetrability of early auditory perception by affect. There are various ways to further investigate this matter, for example by combining the research methods used in the different chapters.

The associations we found between affect and auditory perception may have implications for responses to sounds in our day-to-day environment. For example, speculatively, in daily listening, seemingly purely auditory perceptual experiences of sounds may be infused with affect, which in turn could influence further appraisal of these sounds and perpetuate mood states. These are hypotheses that deserve to be further explored.

To conclude, the findings of this thesis suggest that aspects of basic auditory perception are susceptible to affective influences. This fits with the notion that our brain integrates various sources of perceptual and non-perceptual information, including affective information, in order to create auditory percepts from the often distorted, incomplete or ambiguous input that our auditory senses receive at a given instance. Furthermore, these findings underpin and stimulate research into the mechanisms through which this integration occurs and at which levels of auditory processing in the brain this happens.

References

Adolphs, R. (2017a). How should neuroscience study emotions? By distinguishing emotion states, concepts, and experiences. *Social Cognitive and Affective Neuroscience*, *12*(1), 24–31. https://doi.org/10.1093/scan/nsw153

Adolphs, R. (2017b). Reply to Barrett: Affective neuroscience needs objective criteria for emotions. *Social Cognitive and Affective Neuroscience*, *12*(1), 32–33. https://doi.org/10.1093/scan/nsw155

Aeschlimann, M., Knebel, J. F., Murray, M. M., & Clarke, S. (2008). Emotional pre-eminence of human vocalizations. *Brain Topography*, *20*(4), 239–248. https://doi.org/10.1007/s10548-008-0051-8

Aguado, L., Pierna, M., & Saugar, C. (2005). Affective priming with associatively acquired valence. *Psicológica*, *26*(2), 261–279. Retrieved from https://eric.ed.gov/?id=EJ844427

Al-Abduljawad, K., Baqui, F., Langley, R., Bradshaw, C., & Szabadi, E. (2008). Effects of threat of electric shock and diazepam on the N1/P2 auditory-evoked potential elicited by low-intensity auditory stimuli. *Journal of Psychopharmacology*, *22*(8), 828–835. https://doi.org/10.1177/0269881107083843

Anderson, E., Siegel, E. H., & Barrett, L. F. (2011). What you feel influences what you see: The role of affective feelings in resolving binocular rivalry. *Journal of Experimental Social Psychology*, *47*(4), 856-860. https://doi.org/10.1016/j.jesp.2011.02.009

Anderson, K. J. (1990). Arousal and the inverted-U hypothesis: A critique of Neiss's "Reconceptualizing arousal.". *Psychological Bulletin*, *107*(1), 96–100. https://doi.org/10.1037/0033-2909.107.1.96

Angelucci, A., Levitt, J. B., Walton, E. J. S., Hupé, J.-M., Bullier, J., & Lund, J. S. (2002). Circuits for local and global signal integration in primary visual cortex. *The Journal of Neuroscience*, *22*(19), 8633–8646. https://doi.org/10.1523/jneurosci.22-19-08633.2002

ANSI. (1994). *American national standard acoustical terminology* (ANSI standard No. S1.1-1994). New York, NY: American National Standards Institute.

Aron, E. N., & Aron, A. (1997). Sensory-processing sensitivity and its relation to introversion and emotionality. *Journal of Personality and Social Psychology*, *73*(2), 345–368. https://doi.org/10.1037/0022-3514.73.2.345

Aron, E. N., Aron, A., & Jagiellowicz, J. (2012). Sensory processing sensitivity: A review in the light of the evolution of biological responsivity. *Personality and Social Psychology Review*, *16*(3), 262–282. https://doi.org/10.1177/1088868311434213

ASA. (1960). *Acoustical terminology* (ASA standard No. SI 1-1960). New York, NY: American Standards Association.

Ashby, F. G., Isen, A. M., & Turken, A. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review*, *106*(3), 529–550. https://doi.org/10.1037/0033-295x.106.3.529

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine fucntion: Adaptive gain and optimal performance. *Annual Review of Neuroscience*, *28*(1), 403–450. https://doi.org/10.1146/annurev.neuro.28.061604.135709

Aston-Jones, G., Rajkowski, J., & Cohen, J. (1999). Role of locus coeruleus in attention and behavioral flexibility. *Biological Psychiatry*, *46*(9), 1309–1320. https://doi.org/10.1016/S0006-3223(99)00140-7

Aston-Jones, G., Rajkowski, J., Kubiak, P., Valentino, R. J., & Shipley, M. T. (1996). Role of the locus coeruleus in emotional activation. *Progress in Brain Research*, *107*, 379–402. https://doi.org/10.1016/S0079-6123(08)61877-4

Asutay, E., & Västfjäll, D. (2012). Perception of loudness is influenced by emotion. *PLoS ONE*, *7*(6), 1–5. https://doi.org/10.1371/journal.pone.0038660

Asutay, E., & Västfjäll, D. (2015). Attentional and emotional prioritization of the sounds occurring outside the visual field. *Emotion*, *15*(3), 281–286. https://doi.org/10.1037/emo0000045

Baas, J. M. P., Milstein, J., Donlevy, M., & Grillon, C. (2006). Brainstem correlates of defensive states in humans. *Biological Psychiatry*, *59*(7), 588–593. https://doi.org/10.1016/j.biopsych.2005.09.009

Bachem, A. (1950). Tone height and tone chroma as two different pitch qualities. *Acta Psychologica*, *7*, 80–88. https://doi.org/10.1016/0001-6918(50)90004-7

Bachman, J. G., & O'Malley, P. M. (1984). Yea-saying, nay-saying, and going to extremes: Black- white differences in response styles. *Public Opinion Quarterly*, *48*(2), 491–509. https://doi.org/10.1086/268845

Baeyens, F., Crombez, G., Van den Bergh, O., & Eelen, P. (1988). Once in contact always in contact: Evaluative conditioning is resistant to extinction. *Advances in Behaviour Research and Therapy*, *10*(4), 179–199. https://doi.org/10.1016/0146-6402(88)90014-8

Baeyens, F., Díaz, E., & Ruiz, G. a. (2005). Resistance to extinction of human evaluative conditioning using a between-subjects design. *Cognition & Emotion*, *19*(2), 245–268. https://doi.org/10.1080/02699930441000300

Baeyens, F., Eelen, P., Crombez, G., & van den Bergh, O. (1992). Human evaluative conditioning: Acquisition trials, presentation schedule, evaluative style and contingency awareness. *Behaviour Research and Therapy*, *30*(2), 133–142. https://doi.org/10.1016/0005-7967(92)90136-5

Baeyens, F., Eelen, P., Van den Bergh, O., & Crombez, G. (1990). Flavor-flavor and color-flavor conditioning in humans. *Learning and Motivation*, *21*(4), 434–455. https://doi.org/10.1016/0023-9690(90)90025-J

Baeyens, F., Vansteenwegen, D., & Hermans, D. (2009). Associative learning requires associations, not propositions. *Behavioral and Brain Sciences*, *32*(2), 198–199. https://doi.org/doi:10.1017/S0140525X09000867

Banse, R., & Scherer, K. R. (1996). Acoustic profiles in vocal emotion expression. *Journal of Personality and Social Psychology*, *70*(3), 614–636. https://doi.org/10.1037/0022-3514.70.3.614

Bänziger, T., & Scherer, K. R. (2005). The role of intonation in emotional expressions. *Speech Communication*, *46*(3), 252–267. https://doi.org/10.1016/j.specom.2005.02.016

Bargh, J. A., Chaiken, S., Raymond, P., & Hymes, C. (1996). The automatic evaluation effect: Unconditional automatic attitude activation with a pronunciation task. *Journal of*

Experimental Social Psychology, *32*(1), 104–128. https://doi.org/10.1006/jesp.1996.0005

Barrett, L. F. (2006). Solving the emotion paradox: Categorization and the experience of emotion. *Personality and Social Psychology Review*, *10*(1), 20–46. https://doi.org/10.1207/s15327957pspr1001_2

Barrett, L. F. (2017a). Functionalism cannot save the classical view of emotion. *Social Cognitive and Affective Neuroscience*, *12*(1), 34–36. https://doi.org/10.1093/scan/nsw156

Barrett, L. F. (2017b). The theory of constructed emotion: an active inference account of interoception and categorization. *Social Cognitive and Affective Neuroscience*, *12*(1), 1–23. https://doi.org/10.1093/scan/nsw154

Barrett, L. F., & Bar, M. (2009). See it with feeling: affective predictions during object perception. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1521), 1325–1334. https://doi.org/10.1098/rstb.2008.0312

Barrett, L. F., & Bliss-Moreau, E. (2009). Affect as a psychological primitive. *Advances in Experimental Social Psychology*, *41*, 167–218. https://doi.org/10.1016/S0065-2601(08)00404-8

Bartels, S., Márki, F., & Müller, U. (2015). The influence of acoustical and non-acoustical factors on short-term annoyance due to aircraft noise in the field – the COSMA study. *Science of The Total Environment*, *538*, 834–843. https://doi.org/10.1016/j.scitotenv.2015.08.064

Baumgartner, H., & Steenkamp, J.-B. E. M. (2001). Response styles in marketing research: A cross-national investigation. *Journal of Marketing Research*, *38*(2), 143–156. https://doi.org/10.1509/jmkr.38.2.143.18840

Beck, D. M., & Clevenger, J. (2016). The folly of boxology. *Behavioral and Brain Sciences*, *39*, e231. https://doi.org/10.1017/S0140525X15002630

Beck, D. M., & Kastner, S. (2009). Top-down and bottom-up mechanisms in biasing competition in the human brain. *Vision Research*, *49*(10), 1154–1165. https://doi.org/10.1016/j.visres.2008.07.012

Becker, M. W., & Leinenger, M. (2011). Attentional selection is biased toward mood-congruent stimuli. *Emotion*, *11*(5), 1248–1254. https://doi.org/10.1037/a0023524

Beedie, C., Terry, P., & Lane, A. (2005). Distinctions between emotion and mood. *Cognition and Emotion*, *19*(6), 847–878. https://doi.org/10.1080/02699930541000057

Beevers, C. G., & Carver, C. S. (2003). Attentional bias and mood persistence as prospective predictors of dysphoria. *Cognitive Therapy & Research*, *27*(6), 619–637. https://doi.org/10.1023/A:1026347610928

Bendor, D., Osmanski, M. S., & Wang, X. (2012). Dual-pitch processing mechanisms in primate auditory cortex. *The Journal of Neuroscience*, *32*(46), 16149–16161. https://doi.org/10.1523/jneurosci.2563-12.2012

Berglund, B., Lindvall, T., & Schwela, D. H. (2000). New WHO guidelines for community noise. *Noise & Vibration Worldwide*, *31*(4), 24–29. https://doi.org/10.1260/0957456001497535

Berridge, C. W., & Waterhouse, B. D. (2003). The locus coeruleus-noradrenergic system: Modulation of behavioral state and state-dependent cognitive processes. *Brain Research Reviews*, *42*(1), 33–84. https://doi.org/10.1016/S0165-0173(03)00143-7

Bhalla, M., & Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(4), 1076–1096. https://doi.org/10.1037/0096-1523.25.4.1076

Bliss-Moreau, E., Owren, M. J., & Barrett, L. F. (2010). I like the sound of your voice: Affective learning about vocal signals. *Journal of Experimental Social Psychology*, *46*(3), 557–563. https://doi.org/doi.org/10.1016/j.jesp.2009.12.017

Bocanegra, B. R., & Zeelenberg, R. (2009). Emotion improves and impairs early vision. *Psychological Science*, *20*(6), 707–713. https://doi.org/10.1111/j.1467-9280.2009.02354.x

Boksem, M. A., Tops, M., Kostermans, E., & De Cremer, D. (2008). Sensitivity to punishment and reward omission: Evidence from error-related ERP components. *Biological Psychology*, *79*(2), 185–192. https://doi.org/10.1016/j.biopsycho.2008.04.010

Boksem, M. A., Tops, M., Wester, A. E., Meijman, T. F., & Lorist, M. M. (2006). Error-related ERP components and individual differences in punishment and reward sensitivity. *Brain Research*, *1101*(1), 92–101. https://doi.org/10.1016/j.brainres.2006.05.004

Bolders, A. C., Band, G. P., & Stallen, P. J. M. (2012). Evaluative conditioning induces changes in sound valence. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00106

Bolders, A. C., Band, G. P. H., & Stallen, P. J. M. (2017). Inconsistent effect of arousal on early auditory perception. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00447

Bolders, A. C., Tops, M., Band, G. P. H., & Stallen, P. J. M. (2017). Perceptual sensitivity and response to strong stimuli are related. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.01642

Bolles, R. C., Hulicka, I. M., & Hanly, B. (1959). Colour judgment as a function of stimulus conditions and memory colour. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *13*(3), 175–185. https://doi.org/10.1037/h0083774

Bornschein, S., Hausteiner, C., Zilker, T., & Förstl, H. (2002). Psychiatric and somatic disorders and multiple chemical sensitivity (MCS) in 264 'environmental patients'. *Psychological Medicine*, *32*(08), 1387–1394. https://doi.org/10.1017/S0033291702006554

Borra, T., Versnel, H., Kemner, C., van Opstal, A. J., & van Ee, R. (2013). Octave effect in auditory attention. *Proceedings of the National Academy of Sciences*, *110*(38), 15225–15230. https://doi.org/10.1073/pnas.1213756110

Bosker, H. R. (2018). Putting Laurel and Yanny in context. *The Journal of the Acoustical Society of America*, *144*(6), EL503–EL508. https://doi.org/10.1121/1.5070144

Bowen, M., Terreros, G., Moreno-Gómez, F. N., Ipinza, M., Vicencio, S., Robles, L., & Delano, P. H. (2020). The olivocochlear reflex strength in awake chinchillas is relevant for behavioural performance during visual selective attention with auditory distractors. *Scientific Reports*, *10*(1), 1–11. https://doi.org/10.1038/s41598-020-71399-8

Bower, G. H. (1981). Mood and memory. *American Psychologist*, *36*(2), 129–148. https://doi.org/10.1037/0003-066x.36.2.129

Bower, G. H., & Forgas, J. P. (2000). Affect, memory, and social cognition. In E. Eich, J. F. Kihlstrom, G. H. Bower, J. P. Forgas, & P. M. Niedenthal (Eds.), *Cognition and emotion* (pp. 87–168). New York, NY: Oxford University Press.

Bradley, M. M., & Lang, P. (2007). *The International Affective Digitized Sounds (2nd edition; IADS-2): Affective ratings of sounds and instruction manual* (Technical Report No. B-3). University of Florida, Gainesville, FL.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, *25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Brandt, M. J., Ijzerman, H., Dijksterhuis, A., Farach, F. J., Geller, J., Giner-Sorolla, R., ... van 't Veer, A. (2014). The replication recipe: What makes for a convincing replication? *Journal of Experimental Social Psychology*, *50*, 217–224. https://doi.org/10.1016/j.jesp.2013.10.005

Broadbent, D. E. (1958). *Perception and communication*. Oxford, England: Pergamon Press.

Brogaard, B., & Gatzia, D. (2015). Is the auditory system cognitively penetrable? *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01166

Bruner, J. S. (1992). Another look at New Look 1. *American Psychologist*, *47*(6), 780–783. https://doi.org/10.1037/0003-066X.47.6.780

Bruner, J. S., & Goodman, C. C. (1947). Value and need as organizing factors in perception. *The Journal of Abnormal and Social Psychology*, *42*(1), 33–44. https://doi.org/10.1037/h0058484

Burns, E. M., & Viemeister, N. F. (1976). Nonspectral pitch. *The Journal of the Acoustical Society of America*, *60*(4), 863–869. https://doi.org/10.1121/1.381166

Burns, E. M., & Viemeister, N. F. (1981). Played-again SAM: Further observations on the pitch of amplitude-modulated noise. *The Journal of the Acoustical Society of America*, *70*(6), 1655–1660. https://doi.org/10.1121/1.387220

Canli, T., Zhao, Z., Desmond, J. E., Kang, E., Gross, J., & Gabrieli, J. D. E. (2001). An fMRI study of personality influences on brain reactivity to emotional stimuli. *Behavioral Neuroscience*, *115*(1), 33–42. https://doi.org/10.1037/0735-7044.115.1.33

Carlyon, R. P. (1998). Comments on “A unitary model of pitch perception” [J. Acoust. Soc. Am. 102, 1811-1820 (1997)]. *The Journal of the Acoustical Society of America*, *104*(2), 1118–1121. https://doi.org/10.1121/1.423319

Carlyon, R. P., & Gockel, H. (2008). Effects of harmonicity and regularity on the perception of sound sources. In W. Yost, A. Popper, & R. Fay (Eds.), *Auditory perception of sound sources.* (pp. 191–213). Boston, MA: Springer.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research*, *51*(13), 1484–1525. https://doi.org/10.1016/j.visres.2011.04.012

Cataldo, A. M., & Cohen, A. L. (2015). The effect of emotional state on visual detection: A signal detection analysis. *Emotion*, *15*(6), 846–853. https://doi.org/10.1037/emo0000091

Cave, K. R., & Batty, M. J. (2006). From searching for features to searching for threat: Drawing the boundary between preattentive and attentive vision. *Visual Cognition*, *14*(4), 629–646. https://doi.org/10.1080/13506280500193107

Cecchi, A. S. (2014). *Modularity, cognitive penetration and perceptual justification* (Doctoral dissertation). https://doi.org/10.13097/archive-ouverte/unige:44996

Cecchi, A. S. (2018). Cognitive penetration of early vision in face perception. *Consciousness and Cognition*, *63*, 254–266. https://doi.org/10.1016/j.concog.2018.06.005

Chambers, C., Akram, S., Adam, V., Pelofi, C., Sahani, M., Shamma, S., & Pressnitzer, D. (2017). Prior context in audition informs binding and shapes simple features. *Nature Communications*, *8*(1), 15027. https://doi.org/10.1038/ncomms15027

Chanes, L., & Barrett, L. F. (2016). Redefining the role of limbic areas in cortical processing. *Trends in Cognitive Sciences*, *20*(2), 96–106. https://doi.org/10.1016/j.tics.2015.11.005

Charland, L. (2009). Affect (philosophical perspectives). In D. Sander & K. R. Scherer (Eds.), *The Oxford companion to emotion and the affective sciences* (pp. 9–10). New York, NY: Oxford University Press.

Christison-Lagay, K. L., Bennur, S., & Cohen, Y. E. (2017). Contribution of spiking activity in the primary auditory cortex to detection in noise. *Journal of Neurophysiology*, *118*(6), 3118–3131. https://doi.org/10.1152/jn.00521.2017

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences*, *36*(3), 181–204. https://doi.org/10.1017/S0140525X12000477

Clark, A. (2016). Attention alters predictive processing. *Behavioral and Brain Sciences*, *39*. https://doi.org/10.1017/S0140525X15002472

Clayton, E. C., Rajkowski, J., Cohen, J. D., & Aston-Jones, G. (2004). Phasic activation of monkey locus ceruleus neurons by simple decisions in a forced-choice task. *The Journal of Neuroscience*, *24*(44), 9914–9920. https://doi.org/10.1523/jneurosci.2446-04.2004

Cloninger, C., Svrakic, D. M., & Przybeck, T. R. (1993). A psychobiological model of temperament and character. *Archives of General Psychiatry*, *50*(12), 975–990. https://doi.org/10.1001/archpsyc.1993.01820240059008

Clopton, B. M., Winfield, J. A., & Flammino, F. J. (1974). Tonotopic organization: Review and analysis. *Brain Research*, *76*(1), 1–20. https://doi.org/10.1016/0006-8993(74)90509-5

Clore, G. L., & Robinson, M. D. (2012). Five new ideas about emotion and their implications for social-personality. In K. Deaux & M. Snyder (Eds.), *The Oxford handbook of personality and social psychology* (pp. 315–336). New York, NY: Oxford University Press.

Clore, G. L., & Robinson, M. D. (2018). Five questions about emotion: Implications for social-personality psychology. In K. Deaux & M. Snyder (Eds.), *The Oxford handbook of personality and social psychology* (2nd ed., pp. 365–386). New York, YN: Oxford University Press.

Collier, W., & Hubbard, T. (2001). Judgments of happiness, brightness, speed and tempo change of auditory stimuli varying in pitch and tempo. *Psychomusicology*, *17*, 36–55. https://doi.org/10.1037/h0094060

Corr, P. J. (2004). Reinforcement sensitivity theory and personality. *Neuroscience & Biobehavioral Reviews*, *28*(3), 317–332. https://doi.org/10.1016/j.neubiorev.2004.01.005

Cosmides, L., & Tooby, J. (2000). Evolutionary psychology and the emotions. In M. Lewis & M. Haviland-Jones (Eds.), *Handbook of emotions* (Vol. 2, pp. 91–115). New York, NY: Guilford Press.

Costa, P. T., & McCrae, R. R. (1992). Normal personality assessment in clinical practice: The NEO personality inventory. *Psychological Assessment*, *4*(1), 5–13. https://doi.org/10.1037/1040-3590.4.1.5

Crawford, L. E. (2009). Conceptual metaphors of affect. *Emotion Review*, *1*(2), 129–139. https://doi.org/10.1177/1754073908100438

Crichton, F., Dodd, G., Schmid, G., & Petrie, K. J. (2015). Framing sound: Using expectations to reduce environmental noise annoyance. *Environmental Research*, *142*, 609–614. https://doi.org/10.1016/j.envres.2015.08.016

Crivelli, C., & Fridlund, A. J. (2019). Inside-out: From basic emotions theory to the behavioral ecology view. *Journal of Nonverbal Behavior*, *43*(2), 161–194. https://doi.org/10.1007/s10919-019-00294-2

Cruttenden, A. (1997). *Intonation*. Cambridge, UK: Cambridge University Press.

Dalton, P. (1996). Odor perception and beliefs about risk. *Chemical Senses*, *21*(4), 447–458. https://doi.org/10.1093/chemse/21.4.447

Darwin, C. (2005). Overview: The present and future of pitch. In C. Plack, R. Fay, A. Oxenham, & A. Popper (Eds.), *Pitch: Neural coding and perception* (pp. 278–305). New York, NY: Springer.

de Cheveigné, A. (2005). Pitch perception models. In C. J. Plack, R. R. Fay, A. J. Oxenham, & A. N. Popper (Eds.), *Pitch: Neural coding and perception* (pp. 169–233). New York, NY: Springer.

De Houwer, J. (2003). A structural analysis of indirect measures of attitudes. In J. Musch & K. C. Klauer (Eds.), *The psychology of evaluation. affective processes in cognition and emotion* (pp. 219–244). Mahwah, New Jersey: Lawrence Erlbaum Associates.

De Houwer, J. (2006). What are implicit measures and why are we using them. In R. W. Wiers & A. W. Stacy (Eds.), *The handbook of implicit cognition and addiction* (pp. 11–28).

Thousand Oaks, CA: Sage Publishers.

De Houwer, J. (2007). A conceptual and theoretical analysis of evaluative conditioning. *The Spanish Journal of Psychology*, *10*(2), 230-241. https://doi.org/10.1017/S1138741600006491

De Houwer, J. (2008). Conditioning as a source of liking: There is nothing simple about it. In M. Wänke (Ed.), *Frontiers of social psychology: Social psychology of consumer behavior.* (pp. 151–166). New York: Psychology Press.

De Houwer, J., Baeyens, F., & Field, A. (2005). Associative learning of likes and dislikes: Some current controversies and possible ways forward. *Cognition & Emotion*, *19*(2), 161–174. https://doi.org/10.1080/02699930441000265

De Houwer, J., Teige-Mocigemba, S., Spruyt, A., & Moors, A. (2009). Implicit measures: A normative analysis and review. *Psychological Bulletin*, *135*(3), 347–368. https://doi.org/10.1037/a0014211

De Houwer, J., Thomas, S., & Baeyens, F. (2001). Associative learning of likes and dislikes: A review of 25 years of research on human evaluative conditioning. *Psychological Bulletin*, *127*(6), 853–869. https://doi.org/10.1037/0033-2909.127.6.853

de Ruiter, M. B., Elzinga, B. M., & Phaf, R. H. (2006). Dissociation: Cognitive capacity or dysfunction? *Journal of Trauma & Dissociation*, *7*(4), 115–134. https://doi.org/10.1300/J229v07n04_07

de Ruiter, M. B., Phaf, R. H., Veltman, D. J., Kok, A., & van Dyck, R. (2003). Attention as a characteristic of nonclinical dissociation: an event-related potential study. *NeuroImage*, *19*(2), 376–390. https://doi.org/10.1016/S1053-8119(03)00099-5

Dean, I., Harper, N. S., & McAlpine, D. (2005). Neural population coding of sound level adapts to stimulus statistics. *Nature Neuroscience*, *8*(12), 1684–1689. https://doi.org/10.1038/nn1541

de Gelder, B., & Vroomen, J. (2000). The perception of emotions by ear and by eye. *Cognition & Emotion*, *14*(3), 289–311. https://doi.org/10.1080/026999300378824

Degner, J. (2008). On the (un-)controllability of affective priming: Strategic manipulation is feasible but can possibly be prevented. *Cognition & Emotion*, *23*(2), 327–354. https://doi.org/10.1080/02699930801993924

Delano, P. H., & Elgoyhen, A. B. (2016). Editorial: Auditory efferent system: New insights from cortex to cochlea. *Frontiers in Systems Neuroscience*, *10*. https://doi.org/10.3389/fnsys.2016.00050

Delano, P. H., Elgueda, D., Hamame, C. M., & Robles, L. (2007). Selective attention to visual stimuli reduces cochlear sensitivity in chinchillas. *Journal of Neuroscience*, *27*(15), 4146–4153. https://doi.org/10.1523/JNEUROSCI.3702-06.2007

Delgutte, B. (1990). Physiological mechanisms of psychophysical masking: Observations from auditory-nerve fibers. *The Journal of the Acoustical Society of America*, *87*(2), 791–809. https://doi.org/10.1121/1.398891

Derryberry, D., & Rothbart, M. K. (1988). Arousal, affect, and attention as components of temperament. *Journal of Personality and Social Psychology*, *55*(6), 958–966. https://doi.org/10.1037/0022-3514.55.6.958

Derryberry, D., & Tucker, D. M. (1994). Motivating the focus of attention. In P. Niedenthal & S. Kitayama (Eds.), *The heart's eye emotional influences in perception and attention* (pp. 167–196). San Diego: Academic Press.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*(1), 193–222. https://doi.org/10.1146/annurev.ne.18.030195.001205

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review*, *70*(1), 80–90. https://doi.org/10.1037/h0039515

Devilbiss, D. M. (2019). Consequences of tuning network function by tonic and phasic locus coeruleus output and stress: Regulating detection and discrimination of peripheral stimuli. *Brain Research*, *1709*, 16–27. https://doi.org/10.1016/j.brainres.2018.06.015

Devilbiss, D. M., & Waterhouse, B. D. (2004). The effects of tonic locus ceruleus output on sensory-evoked responses of ventral posterior medial thalamic and barrel field cortical neurons in the awake rat. *The Journal of Neuroscience*, *24*(48), 10773–10785. https://doi.org/10.1523/jneurosci.1573-04.2004

Devinsky, O., Morrell, M. J., & Vogt, B. A. (1995). Contributions of anterior cingulate cortex to behaviour. *Brain*, *118*(1), 279–306. https://doi.org/10.1093/brain/118.1.279

Duncan, J. (2006). EPS mid-career award 2004: Brain mechanisms of attention. *The Quarterly Journal of Experimental Psychology*, *59*(1), 2–27. https://doi.org/10.1080/17470210500260674

Dunning, D., & Balcetis, E. (2013). Wishful seeing: How preferences shape visual perception. *Current Directions in Psychological Science*, *22*(1), 33–37. https://doi.org/10.1177/0963721412463693

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review*, *66*(3), 183–201. https://doi.org/10.1037/h0047707.

Edeline, J.-M., Manunta, Y., & Hennevin, E. (2011). Induction of selective plasticity in the frequency tuning of auditory cortex and auditory thalamus neurons by locus coeruleus stimulation. *Hearing Research*, *274*(1-2), 75–84. https://doi.org/10.1016/j.heares.2010.08.005

Eder, A. B., & Rothermund, K. (2008). When do motor behaviors (mis)match affective stimuli? An evaluative coding view of approach and avoidance reactions. *Journal of Experimental Psychology: General*, *137*(2), 262–281. https://doi.org/10.1037/0096-3445.137.2.262

Edman, G., Schalling, D., & Rissler, A. (1979). Interaction effects of extraversion and neuroticism on detection thresholds. *Biological Psychology*, *9*(1), 41–47. https://doi.org/10.1016/0301-0511(79)90021-8

Eich, E., Ng, J., Macaulay, D., Percy, A., & Grebneva, I. (2007). Combining music with thought to change mood. In J. Coan & J. B. Allen (Eds.), *Handbook of emotion elicitation and assessment* (pp. 124–136). New York, NY: Oxford University Press.

Ekman, P. (1994). Moods, emotions, and traits. In P. Ekman & R. J. Davidson (Eds.), *The nature of emotion: Fundamental questions* (pp. 56–58). New York, NY: Oxford University Press.

Ekman, P. (2003). *Emotions revealed: recognizing faces and feelings to improve communication and emotional life*. New York, NY: Times Books/Henry Holt and Co.

Ekman, P., & Cordaro, D. (2011). What is meant by calling emotions basic. *Emotion Review*, *3*(4), 364–370. https://doi.org/10.1177/1754073911410740

Elberling, C., Bak, C., Kofoed, B., Lebech, J., & Sœrmark, K. (1982). Auditory magnetic fields: Source location and ‘tonotopical organization’ in the right hemisphere of the human brain. *Scandinavian Audiology*, *11*(1), 61–65. https://doi.org/10.3109/01050398209076201

Ellermeier, W., Eigenstetter, M., & Zimmer, K. (2001). Psychoacoustic correlates of individual noise sensitivity. *The Journal of the Acoustical Society of America*, *109*(4), 1464–1473. https://doi.org/10.1121/1.1350402

Erdelyi, M. H. (1974). A new look at the New Look: Perceptual defense and vigilance. *Psychological Review*, *81*(1), 1–25. https://doi.org/10.1037/h0035852

Evans, D. E., & Rothbart, M. K. (2007). Developing a model for adult temperament. *Journal of Research in Personality*, *41*(4), 868–888. https://doi.org/10.1016/j.jrp.2006.11.002

Evans, D. E., & Rothbart, M. K. (2008). Temperamental sensitivity: Two constructs or one? *Personality and Individual Differences*, *44*(1), 108–118. https://doi.org/10.1016/j.paid.2007.07.016

Eysenck, H. J. (1967). *The biological basis of personality*. Springfield, IL: Charles C. Thomas.

Eysenck, H. J., & Eysenck, S. B. G. (1975). *EPQ (Eysenck Personality Questionnaire)*. Educational and Industrial Testing Service.

Fabiani, M., Kazmerski, V. A., Cycowicz, Y., & Friedman, D. D. (1996). Naming norms for brief environmental sounds: Effects of age and dementia. *Psychophysiology*, *33*, 462–475. https://doi.org/10.1111/j.1469-8986.1996.tb01072.x

Fant, G. (1960). *Acoustic theory of speech production*. The Hague, The Netherlands: Mouton.

Fastl, H. (2001). Neutralizing the meaning of sound for sound quality evaluations. In *Proceedings of the 17th International Congress on Acoustics*. Retrieved from http://www.icacommission.org/Proceedings/ICA2001Rome/8_10.pdf

Fastl, H., Menzel, D., & Krause, M. (2006). Loudness thermometer: evidence for cognitive effects? [DVD]. In *Proceedings of the 35th international congress and exposition on noise control engineering*. Washington, DC: The Institute of Noise Control Engineering of the USA.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/bf03193146

Fazio, R. H., & Olson, M. A. (2003). Implicit measures in social cognition research: Their meaning and use. *Annual Review of Psychology*, *54*(1), 297–327. https://doi.org/doi:10.1146/annurev.psych.54.101601.145225

Feldman, H., & Friston, K. (2010). Attention, uncertainty, and free-energy. *Frontiers in Human Neuroscience*, *4*. https://doi.org/10.3389/fnhum.2010.00215

Felix, R. A., II, Gourévitch, B., & Portfors, C. V. (2018). Subcortical pathways: Towards a better understanding of auditory disorders. *Hearing Research*, *362*, 48–60. https://doi.org/10.1016/j.heares.2018.01.008

Feyerabend, P. (1962). Explanation, reduction and empiricism. In H. Feigl & M. G. (Eds.), *Minnesota studies in philosophy of science* (Vol. 3, pp. 28–97). Minneapolis, MN: University of Minnesota Press.

Field, A. P. (2005). Learning to like (or dislike): Associative learning of preferences. In A. J. Wills (Ed.), *New directions in human associative learning* (pp. 221–252). Mahwah: New Jersey: Lawrence Erlbaum Associates.

Firestone, C., & Scholl, B. J. (2016). Cognition does not affect perception: Evaluating the evidence for "top-down" effects. *Behavioral and Brain Sciences*, *39*, e229. https://doi.org/10.1017/S0140525X15000965

Fletcher, H., & Munson, W. A. (1933). Loudness, its definition, measurement and calculation*. *Bell System Technical Journal*, *12*(4), 377–430. https://doi.org/10.1002/j.1538-7305.1933.tb00403.x

Fodor, J. A. (1983). *The modularity of mind: An essay on faculty psychology*. Cambridge, MA: MIT press.

Fontaine, J. (2009). Dimensional emotion models. In D. Sander & K. R. Scherer (Eds.), *The Oxford companion to emotion and the affective sciences* (pp. 119–120). New York, NY: Oxford University Press.

Formisano, E., Kim, D.-S., Di Salle, F., van de Moortele, P.-F., Ugurbil, K., & Goebel, R. (2003). Mirror-symmetric tonotopic maps in human primary auditory cortex. *Neuron*, *40*(4), 859–869. https://doi.org/10.1016/S0896-6273(03)00669-X

Forstmann, B., Ratcliff, R., & Wagenmakers, E.-J. (2016). Sequential sampling models in cognitive neuroscience: Advantages, applications, and extensions. *Annual Review of Psychology*, *67*(1), 641–666. https://doi.org/10.1146/annurev-psych-122414-033645

Fox, E. (2008). *Emotion science cognitive and neuroscientific approaches to understanding human emotions*. New York, NY: Palgrave Macmillan.

Fox, E. (2018). Perspectives from affective science on understanding the nature of emotion. *Brain and Neuroscience Advances*, *2*. https://doi.org/10.1177/2398212818812628

Fredrickson, B. L. (2004). The broaden-and-build theory of positive emotions. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *359*(1449), 1367–1377. https://doi.org/10.1098/rstb.2004.1512

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. *Cognition & Emotion*, *19*(3), 313–332. https://doi.org/10.1080/02699930441000238

Friedman, R. S., Neill, W. T., Seror, G. A., & Kleinsmith, A. L. (2018). Average pitch height and perceived emotional expression within an unconventional tuning system. *Music Perception: An Interdisciplinary Journal*, *35*(4), 518–523. https://doi.org/10.1525/mp.2018.35.4.518

Frijda, N. H. (1993). Moods, emotion episodes, and emotions. In M. Lewis & J. M. Haviland (Eds.), *Handbook of emotions.* (pp. 381–403). New York, NY: Guilford Press.

Frijda, N. H. (2009). Mood. In D. Sander & K. R. Scherer (Eds.), *The Oxford companion to emotion and the affective sciences* (pp. 258–259). New York, NY: Oxford University Press.

Frijda, N. H., & Scherer, K. R. (2009). Affect (psychological perspectives). In D. Sander & K. R. Scherer (Eds.), *The Oxford companion to emotion and the affective sciences* (p. 10). New York, NY: Oxford University Press.

Friston, K. (2005). A theory of cortical responses. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1465), 815–836. https://doi.org/10.1098/rstb.2005.1622

Friston, K. (2010). The free-energy principle: a unified brain theory? *Nature Reviews Neuroscience*, *11*(2), 127–138. https://doi.org/10.1038/nrn2787

Friston, K. (2018). Does predictive coding have a future? *Nature Neuroscience*, *21*(8), 1019–1021. https://doi.org/10.1038/s41593-018-0200-7

Fritz, J. B., Elhilali, M., David, S. V., & Shamma, S. A. (2007). Does attention play a role in dynamic receptive field adaptation to changing acoustic salience in A1? *Hearing Research*, *229*(1-2), 186–203. https://doi.org/10.1016/j.heares.2007.01.009

Frost, R. O., & Green, M. L. (1982). Velten mood induction procedure effects. *Personality and Social Psychology Bulletin*, *8*(2), 341–347. https://doi.org/10.1177/0146167282082024

Furnham, A., & Henderson, M. (1982). The good, the bad and the mad: Response bias in self-report measures. *Personality and Individual Differences*, *3*(3), 311–320. https://doi.org/10.1016/0191-8869(82)90051-4

Galambos, R., & Davis, H. (1943). The response of single auditory-nerve fibers to acoustic stimulation. *Journal of Neurophysiology*, *6*(1), 39–57. https://doi.org/10.1152/jn.1943.6.1.39

Gamond, L., George, N., Lemaréchal, J.-D., Hugueville, L., Adam, C., & Tallon-Baudry, C. (2011). Early influence of prior experience on face perception. *NeuroImage*, *54*(2), 1415–1426. https://doi.org/10.1016/j.neuroimage.2010.08.081

García-Blanco, A. C., Perea, M., & Livianos, L. (2013). Mood-congruent bias and attention shifts in the different episodes of bipolar disorder. *Cognition and Emotion*, *27*(6), 1114–1121. https://doi.org/10.1080/02699931.2013.764281

García-Pérez, M. A. (1998). Forced-choice staircases with fixed step sizes: Asymptotic and small-sample properties. *Vision Research*, *38*(12), 1861–1881. https://doi.org/10.1016/S0042-6989(97)00340-4

García-Pérez, M. A., & Alcalá-Quintana, R. (2011). Interval bias in 2AFC detection tasks: Sorting out the artifacts. *Attention, Perception & Psychophysics*, *73*(7), 2332–2352. https://doi.org/10.3758/s13414-011-0167-x

Gardumi, A., Ivanov, D., Havlicek, M., Formisano, E., & Uludağ, K. (2017). Tonotopic maps in human auditory cortex using arterial spin labeling. *Human Brain Mapping*, *38*(3), 1140–1154. https://doi.org/10.1002/hbm.23444

Garrido, S. (2014). A systematic review of the studies measuring mood and emotion in response to music. *Psychomusicology: Music, Mind, and Brain*, *24*(4), 316–327. https://doi.org/10.1037/pmu0000072

Gasper, K. (2004). Do you see what I see? Affect and visual information processing. *Cognition & Emotion*, *18*(3), 405–421. https://doi.org/10.1080/02699930341000068

Gasper, K., & Clore, G. L. (2002). Attending to the big picture: Mood and global versus local processing of visual information. *Psychological Science*, *13*(1), 34–40. https://doi.org/10.1111/1467-9280.00406

Gawronski, B. (2009). Ten frequently asked questions about implicit measures and their frequently supposed, but not entirely correct answers. *Canadian Psychology/Psychologie Canadienne,*, *50*(3), 141–150. https://doi.org/10.1037/a0013848

Gawronski, B., & Bodenhausen, G. V. (2011). The associative-propositional evaluation model: Theory, evidence, and open questions. *Advances in Experimental Social Psychology*, *44*, 59–127. https://doi.org/10.1016/B978-0-12-385522-0.00002-0

Gawronski, B., & De Houwer, J. (2014). Implicit measures in social and personality psychology. In *Handbook of research methods in social and personality psychology* (2nd ed., pp. 283–310). New York, NY: Cambridge University Press.

Gawronski, B., & Hahn, A. (2019). Implicit measures: Procedures, use, and interpretation. In H. Blanton, J. M. LaCroix, & G. D. Webster (Eds.), (pp. 29–55). New York, NY: Taylor & Francis.

Gerbino, W., & Fantoni, C. (2016). Action valence and affective perception. *Behavioral and Brain Sciences*, *39*. https://doi.org/10.1017/S0140525X15002605

Gescheider, G. A. (1985). *Psychophysics: Method, theory, and application* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.

Gilbert, C. D., & Li, W. (2013). Top-down influences on visual processing. *Nature Reviews Neuroscience*, *14*(5), 350–363. https://doi.org/10.1038/nrn3476

Gillmeister, H., & Eimer, M. (2007). Tactile enhancement of auditory detection and perceived loudness. *Brain Research*, *1160*, 58–68. https://doi.org/10.1016/j.brainres.2007.03.041

Glisky, M. L., Tataryn, D. J., Tobias, B. A., Kihlstrom, J. F., & McConkey, K. M. (1991). Absorption, openness to experience, and hypnotizability. *Journal of Personality and Social Psychology*, *60*(2), 263–272. https://doi.org/10.1037/0022-3514.60.2.263

Gockel, H., Carlyon, R. P., & Plack, C. J. (2004). Across-frequency interference effects in fundamental frequency discrimination: Questioning evidence for two pitch mechanisms. *The Journal of the Acoustical Society of America*, *116*(2), 1092–1104. https://doi.org/10.1121/1.1766021

Goerlich, K. S., Witteman, J., Schiller, N. O., Van Heuven, V. J., Aleman, A., & Martens, S. (2012). The nature of affective priming in music and speech. *Journal of Cognitive Neuroscience*, *24*(8), 1725–1741. https://doi.org/10.1162/jocn_a_00213

Gohm, C. L., & Clore, G. L. (2000). Individual differences in emotional experience: Mapping available scales to processes. *Personality and Social Psychology Bulletin*, *26*(6), 679–697. https://doi.org/10.1177/0146167200268004

Gold, J. I., & Shadlen, M. N. (2007). The neural basis of decision making. *Annual Review of Neuroscience*, *30*(1), 535–574. https://doi.org/10.1146/annurev.neuro.29.051605.113038

Goldstein, J. L. (1973). An optimum processor theory for the central formation of the pitch of complex tones. *The Journal of the Acoustical Society of America*, *54*(6), 1496–1516. https://doi.org/10.1121/1.1914448

Graveling, R. A., Pilkington, A., George, J. P., Butler, M. P., & Tannahill, S. N. (1999). A review of multiple chemical sensitivity. *Occupational and Environmental Medicine*, *56*(2), 73–85. https://doi.org/10.1136/oem.56.2.73

Gray, E., & Watson, D. (2007). Assessing positive and negative affect via self-report. In J. Coan & J. B. Allen (Eds.), *Handbook of emotion elicitation and assessment* (pp. 124–136). New York: Oxford University Press.

Gray, J. A. (1970). The psychophysiological basis of introversion-extraversion. *Behaviour Research and Therapy*, *8*(3), 249–266. https://doi.org/10.1016/0005-7967(70)90069-0

Gray, J. A. (1989). Fundamental systems of emotion in the mammalian brain. In D. Palermo (Ed.), *Coping with uncertainty: Behavioral and developmental perspectives* (pp. 173–195). Hillsdale, NJ: Lawrence Erlbaum.

Gray, J. A., & MacNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system* (2nd ed.). Oxford, United Kingdom: Oxford University Press.

Green, D., & Swets, J. A. (1966). *Signal detection theory and psychophysics.* New York, NY: Wiley.

Greenwood, D. D. (1990). A cochlear frequency-position function for several species-29 years later. *The Journal of the Acoustical Society of America*, *87*(6), 2592–2605. https://doi.org/10.1121/1.399052

Gross, J. J., Sutton, S. K., & Ketelaar, T. (1998). Relations between affect and personality: Support for the affect-level and affective-reactivity views. *Personality and Social Psychology Bulletin*, *24*(3), 279–288. https://doi.org/10.1177/0146167298243005

Gross, S. (2017). Cognitive penetration and attention. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00221

Guski, R. (1999). Personal and social variables as co-determinants of noise annoyance. *Noise and Health*, *1*(3), 45–56. Retrieved from http://www.noiseandhealth.org/article.asp?issn=1463-1741;year=1999;volume=1;issue=3;spage=45;epage=56;aulast=guski

Guski, R., Felscher-Suhr, U., & Schuemer, R. (1999). The concept of noise annoyance: How international experts see it. *Journal of Sound and Vibration*, *223*(4), 513–527. https://doi.org/10.1006/jsvi.1998.2173

Guyer, J. J., Fabrigar, L. R., & Vaughan-Johnston, T. I. (2019). Speech rate, intonation, and pitch: Investigating the bias and cue effects of vocal confidence on persuasion. *Personality and Social Psychology Bulletin*, *45*(3), 389–405. https://doi.org/10.1177/0146167218787805

Gygi, B., Kidd, G., & Watson, C. (2007). Similarity and categorization of environmental sounds. *Perception and Psychophysics*, *69*(6), 839–855. https://doi.org/10.3758/BF03193921

Hackel, L. M., Larson, G. M., Bowen, J. D., Ehrlich, G. A., Mann, T. C., Middlewood, B., … Barrett, L. F. (2016). On the neural implausibility of the modular mind: Evidence for distributed construction dissolves boundaries between perception, cognition, and emotion. *Behavioral and Brain Sciences*, *39*. https://doi.org/10.1017/S0140525X15002770

Hairston, W. D., & Maldjian, J. A. (2009). An adaptive staircase procedure for the E-prime programming environment. *Computer Methods and Programs in Biomedicine*, *93*(1), 104–108. https://doi.org/10.1016/j.cmpb.2008.08.003

Halpern, D., Blake, R., & Hillenbrand, J. (1986). Psychoacoustics of a chilling sound. *Attention, Perception, & Psychophysics*, *39*(2), 77–80. https://doi.org/10.3758/bf03211488

Hansen, T., Olkkonen, M., Walter, S., & Gegenfurtner, K. R. (2006). Memory modulates color appearance. *Nature Neuroscience*, *9*(11), 1367–1368. https://doi.org/10.1038/nn1794

Harkness, D. L., & Keshava, A. (2017). Moving from the what to the how and where - Bayesian models and predictive processing. In T. K. Metzinger & W. Wiese (Eds.), *Philosophy and predictive processing* (chap. 16). Frankfurt am Main: MIND Group. https://doi.org/10.15502/9783958573178

Hartman, C., & Majdandžić, M. (2001). *The Dutch translation of Adult Temperament Questionnaire, internal document in Dutch* [Unpublished Work]. Retrieved from https://research.bowdoin.edu/rothbart-temperament-questionnaires/instrument-descriptions/the-adult-temperament-questionnaire/

Hayes, D. J., Duncan, N. W., Xu, J., & Northoff, G. (2014). A comparison of neural responses to appetitive and aversive stimuli in humans and other mammals. *Neuroscience & Biobehavioral Reviews*, *45*, 350–368. https://doi.org/10.1016/j.neubiorev.2014.06.018

Hayes, D. J., & Northoff, G. (2012). Common brain activations for painful and non-painful aversive stimuli. *BMC Neuroscience*, *13*(1), 60–77. https://doi.org/10.1186/1471-2202-13-60

Heekeren, H. R., Marrett, S., & Ungerleider, L. G. (2008). The neural systems that mediate human perceptual decision making. *Nature Reviews Neuroscience*, *9*(6), 467–479. https://doi.org/10.1038/nrn2374

Heil, P., & Peterson, A. J. (2015). Basic response properties of auditory nerve fibers: a review. *Cell and Tissue Research*, *361*(1), 129–158. https://doi.org/10.1007/s00441-015-2177-9

Heilbron, M., & Chait, M. (2018). Great expectations: Is there evidence for predictive coding in auditory cortex? *Neuroscience*, *389*, 54–73. https://doi.org/10.1016/j.neuroscience.2017.07.061

Helmholtz, H. L. F. (2009). *On the sensations of tone as a physiological basis for the theory of music* (A. J. Ellis, Trans.). Cambridge, UK: Cambridge University Press (original work (3rd ed) published in 1870). https://doi.org/10.1017/CBO9780511701801

Hermans, D., Baeyens, F., & Eelen, P. (2003). On the acquisition and activation of evaluative information in memory: The study of evaluative learning and affective priming combined. In J. Musch & K. C. Klauer (Eds.), *The psychology of evaluation. affective processes in cognition and emotion* (pp. 139–168). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Hermans, D., & De Houwer, J. (1994). Affective and subjective famililarity ratings of 740 Dutch words. *Psychologica Belgica*, *34*(2/3), 115–139.

Hermans, D., De Houwer, J., & Eelen, P. (2001). A time course analysis of the affective priming effect. *Cognition & Emotion*, *15*(2), 143–165. https://doi.org/10.1080/02699930125768

Hermans, D., Spruyt, A., & Eelen, P. (2003). Automatic affective priming of recently acquired stimulus valence: Priming at SOA 300 but not at SOA 1000. *Cognition & Emotion*, *17*(1), 83–99. https://doi.org/10.1080/02699930302276

Hillert, L., Jovanovic, H., Åhs, F., & Savic, I. (2013). Women with multiple chemical sensitivity have increased harm avoidance and reduced 5-HT1A receptor binding potential in the anterior cingulate and amygdala. *PLoS ONE*, *8*(1), 1–10. https://doi.org/10.1371/journal.pone.0054781

Hofmann, W., De Houwer, J., Perugini, M., Baeyens, F., & Crombez, G. (2010). Evaluative conditioning in humans: A meta-analysis. *Psychological Bulletin*, *136*(3), 390–421. https://doi.org/10.1037/a0018916

Hohwy, J. (2012). Attention and conscious perception in the hypothesis testing brain. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00096

Hohwy, J. (2017). Priors in perception: Top-down modulation, Bayesian perceptual learning rate, and prediction error minimization. *Consciousness and Cognition*, *47*, 75–85. https://doi.org/10.1016/j.concog.2016.09.004

Horstmann, G. (2010). Tone-affect compatibility with affective stimuli and affective responses. *The Quarterly Journal of Experimental Psychology*, *63*(11), 2239–2250. https://doi.org/10.1080/17470211003687538

Houtsma, A. J. M., & Smurzynski, J. (1990). Pitch identification and discrimination for complex tones with many harmonics. *The Journal of the Acoustical Society of America*, *87*(1), 304–310. https://doi.org/10.1121/1.399297

Hsu, C.-T., Conrad, M., & Jacobs, A. M. (2014). Fiction feelings in Harry Potter: Haemodynamic response in the mid-cingulate cortex correlates with immersive reading experience. *NeuroReport*, *25*(17), 1356–1361. https://doi.org/10.1097/WNR.0000000000000272

Huang, C., Englitz, B., Shamma, S., & Rinzel, J. (2015). A neuronal network model for context-dependence of pitch change perception. *Frontiers in Computational Neuroscience*, *9*. https://doi.org/10.3389/fncom.2015.00101

Hunter, P., Schellenberg, E. G., & Schimmack, U. (2010). Feelings and perceptions of happiness and sadness induced by music: Similarities, differences, and mixed emotions. *Psychology of Aesthetics, Creativity, and the Arts*, *4*(1), 47–56. https://doi.org/10.1037/a0016873

Hunter, P. G., Schellenberg, E. G., & Griffith, A. T. (2011). Misery loves company: Mood-congruent emotional responding to music. *Emotion*, *11*(5), 1068–1072. https://doi.org/10.1037/a0023749

Hyman, L. M. (2001). Tone systems: Typology and description. In M. Haspelmath (Ed.), *Language typology and language universals: An international handbook* (Vol. 2, pp. 1367–1380.). Berlin, Germany: Walter de Gruyter.

Isen, A. M., Clark, M., & Schwartz, M. F. (1976). Duration of the effect of good mood on helping: "Footprints on the sands of time.". *Journal of Personality and Social Psychology*, *34*(3), 385–393. https://doi.org/10.1037/0022-3514.34.3.385

Isen, A. M., & Gorgoglione, J. M. (1983). Some specific effects of four affect-induction procedures. *Personality and Social Psychology Bulletin*, *9*(1), 136–143. https://doi.org/10.1177/0146167283091019

Izard, C. E. (1977). *Human emotions*. New York: Springer.

Izard, C. E. (2007). Basic emotions, natural kinds, emotion schemas, and a new paradigm. *Perspectives on Psychological Science*, *2*(3), 260–280. https://doi.org/10.1111/j.1745-6916.2007.00044.x

Izard, C. E. (2011). Forms and functions of emotions: Matters of emotion-cognition interactions. *Emotion Review*, *3*(4), 371–378. https://doi.org/10.1177/1754073911410737

Jagiellowicz, J., Xu, X., Aron, A., Aron, E., Cao, G., Feng, T., & Weng, X. (2011). The trait of sensory processing sensitivity and neural responses to changes in visual scenes. *Social Cognitive and Affective Neuroscience*, *6*(1), 38–47. https://doi.org/10.1093/scan/nsq001

Jefferies, L. N., Smilek, D., Eich, E., & Enns, J. T. (2008). Emotional valence and arousal interact in attentional control. *Psychological Science*, *19*(3), 290–295. https://doi.org/

10.1111/j.1467-9280.2008.02082.x

Jepma, M., & Nieuwenhuis, S. (2011). Pupil diameter predicts changes in the exploration-exploitation trade-off: Evidence for the adaptive gain theory. *Journal of Cognitive Neuroscience*, *23*(7), 1587–1596. https://doi.org/10.1162/jocn.2010.21548%M20666595

Job, R. F. S. (1988). Community response to noise: A review of factors influencing the relationship between noise exposure and reaction. *The Journal of the Acoustical Society of America*, *83*(3), 991–1001. https://doi.org/10.1121/1.396524

Johnson, D. H. (1980). The relationship between spike rate and synchrony in responses of auditory-nerve fibers to single tones. *The Journal of the Acoustical Society of America*, *68*(4), 1115–1122. https://doi.org/10.1121/1.384982

Jones, P. R., Moore, D. R., Shub, D. E., & Amitay, S. (2015). The role of response bias in perceptual learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(5), 1456–1470. https://doi.org/10.1037/xlm0000111

Joseph, D. L., Chan, M. Y., Heintzelman, S. J., Tay, L., Diener, E., & Scotney, V. S. (2020). The manipulation of affect: A meta-analysis of affect induction procedures. *Psychological Bulletin*, *146*(4), 355–375. https://doi.org/10.1037/bul0000224

Juslin, P. N., & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioral and Brain Sciences*, *31*(05), 559–575. https://doi.org/10.1017/S0140525X08005293

Kaernbach, C., & Bering, C. (2001). Exploring the temporal mechanism involved in the pitch of unresolved harmonics. *The Journal of the Acoustical Society of America*, *110*(2), 1039–1048. https://doi.org/10.1121/1.1381535

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, N. J.: Prentice-Hall.

Kanouse, D. E., & Hanson, L. (1972). Negativity in evaluations. In E. E. Jones, D. E. Kanouse, S. Valins, H. H. Kelley, R. E. Nisbett, & B. Weiner (Eds.), *Attribution: Perceiving the causes of behavior* (pp. 47–62). Morris- town, NJ: General Learning Press.

Kawase, T., Delgutte, B., & Liberman, M. C. (1993). Antimasking effects of the olivocochlear reflex II. enhancement of auditory-nerve response to masked tones. *Journal of Neurophysiology*, *70*(6), 2533–2549. https://doi.org/10.1152/jn.1993.70.6.2533

Keil, A., & Freund, A. M. (2009). Changes in the sensitivity to appetitive and aversive arousal across adulthood. *Psychology and Aging*, *24*(3), 668–680. https://doi.org/10.1037/a0016969

Keil, A., Stolarova, M., Moratti, S., & Ray, W. J. (2007). Adaptation in human visual cortex as a mechanism for rapid discrimination of aversive stimuli. *NeuroImage*, *36*(2), 472–479. https://doi.org/10.1016/j.neuroimage.2007.02.048

Kelly, S. P., & O'Connell, R. G. (2015). The neural processes underlying perceptual decision making in humans: Recent progress and future directions. *Journal of Physiology-Paris*, *109*(1), 27–37. https://doi.org/10.1016/j.jphysparis.2014.08.003

Keltner, D., Tracy, J. L., Sauter, D., & Cowen, A. (2019). What basic emotion theory really says for the twenty-first century study of emotion. *Journal of Nonverbal Behavior*, *43*(2), 195–201. https://doi.org/10.1007/s10919-019-00298-y

Kersten, D., & Yuille, A. (2003). Bayesian models of object perception. *Current Opinion in Neurobiology*, *13*(2), 150–158. https://doi.org/10.1016/S0959-4388(03)00042-4

Kiang, N., Watanabe, T., Thomas, E. C., & Clark, L. F. (1965). *Discharge patterns of single fibers in the cat's auditory nerve*. Cambridge, MA: Massachusetts Institute of Technology Press. Retrieved from https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19660030628.pdf

King, A. J., Teki, S., & Willmore, B. D. B. (2018). Recent advances in understanding the auditory cortex. *F1000Research*, *7*, F1000 Faculty Rev-1555. https://doi.org/10.12688/

f1000research.15580.1

Kingdom, F. A., & Prins, N. (2010). *Psychophysics: A practical introduction* (1st ed.). London, UK: Academic Press.

Klein, S. A. (2001). Measuring, estimating, and understanding the psychometric function: A commentary. *Perception & Psychophysics*, *63*(8), 1421–1455. https://doi.org/10.3758/BF03194552

Klemfuss, N., Prinzmetal, B., & Ivry, R. (2012). How does language change perception: A cautionary note. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00078

Klink, P. C., van Wezel, R. J. A., & van Ee, R. (2012). United we sense, divided we fail: context-driven perception of ambiguous visual stimuli. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1591), 932–941. https://doi.org/10.1098/rstb.2011.0358

Koster, E. H. W., De Raedt, R., Goeleven, E., Franck, E., & Crombez, G. (2005). Mood-congruent attentional bias in dysphoria: Maintained attention to and impaired disengagement from negative information. *Emotion*, *5*(4), 446–455. https://doi.org/10.1037/1528-3542.5.4.446

Krantz, D. H. (1969). Threshold theories of signal detection. *Psychological Review*, *76*(3), 308–324. https://doi.org/10.1037/h0027238

Kuchibhotla, K., & Bathellier, B. (2018). Neural encoding of sensory and behavioral complexity in the auditory cortex. *Current Opinion in Neurobiology*, *52*, 65–71. https://doi.org/10.1016/j.conb.2018.04.002

Kuhbandner, C., Hanslmayr, S., Maier, M. A., Pekrun, R., Spitzer, B., Pastötter, B., & Bäuml, K.-H. (2009). Effects of mood on the speed of conscious perception: behavioural and electrophysiological evidence. *Social Cognitive and Affective Neuroscience*, *4*(3), 286–293. https://doi.org/10.1093/scan/nsp010

Kuhbandner, C., & Zehetleitner, M. (2011). Dissociable effects of valence and arousal in adaptive executive control. *PLoS ONE*, *6*(12), e29287. https://doi.org/10.1371/journal.pone.0029287

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, Il: University of Chicago Press.

Ladd, D. R. (2008). *Intonational phonology* (2nd ed.). Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9780511808814

Ladd, D. R., Turnbull, R., Browne, C., Caldwell-Harris, C., Ganushchak, L., Swoboda, K., . . . Dediu, D. (2013). Patterns of individual differences in the perception of missing-fundamental tones. *Journal of Experimental Psychology: Human Perception and Performance*. https://doi.org/10.1037/a0031261

Laguitton, V., Demany, L., Semal, C., & Liégeois-Chauvel, C. (1998). Pitch perception: a difference between right- and left-handed listeners. *Neuropsychologia*, *36*(3), 201–207. https://doi.org/10.1016/s0028-3932(97)00122-x

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago, IL: University of Chicago Press.

Lamichhane, B., & Dhamala, M. (2015). The salience network and its functional architecture in a perceptual decision: An effective connectivity study. *Brain Connectivity*, *5*(6), 362–370. https://doi.org/10.1089/brain.2014.0282

Lamme, V. A. F. (2003). Why visual attention and awareness are different. *Trends in Cognitive Sciences*, *7*(1), 12–18. https://doi.org/10.1016/S1364-6613(02)00013-X

Lang, P., Bradley, M. M., & Cuthbert, B. (2005). *International Affective Picture system (IAPS): Affective ratings of pictures and instruction manual* (Technical Report No. A-6).

Gainesville, FL: University of Florida.
Langers, D. R., & van Dijk, P. (2012). Mapping the tonotopic organization in human auditory cortex with minimally salient acoustic stimulation. *Cerebral Cortex*, *22*(9), 2024–2038. https://doi.org/10.1093/cercor/bhr282
Larsen, R. J., & Diener, E. (1992). Promises and problems with the circumplex model of emotion. In *Emotion.* (pp. 25–59). Thousand Oaks, CA: Sage Publications, Inc.
Lavender, T., & Hommel, B. (2007). Affect and action: Towards an event-coding account. *Cognition and Emotion*, *21*(6), 1270–1296. https://doi.org/10.1080/02699930701438152
Lee, J., & Maunsell, J. H. R. (2009). A normalization model of attentional modulation of single unit responses. *PLoS ONE*, *4*(2), 1–13. https://doi.org/10.1371/journal.pone.0004651
Lee, S. W. S., & Schwarz, N. (2012). Bidirectionality, mediation, and moderation of metaphorical effects: The embodiment of social suspicion and fishy smells. *Journal of Personality and Social Psychology*, *103*(5), 737–749. https://doi.org/10.1037/a0029708
Lee, T.-H., Baek, J., Lu, Z.-L., & Mather, M. (2014). How arousal modulates the visual contrast sensitivity function. *Emotion*, *14*(5), 978–984. https://doi.org/10.1037/a0037047
Lee, T.-H., Itti, L., & Mather, M. (2012). Evidence for arousal-biased competition in perceptual learning. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00241
Lee, T.-H., Sakaki, M., Cheng, R., Velasco, R., & Mather, M. (2014). Emotional arousal amplifies the effects of biased competition in the brain. *Social Cognitive and Affective Neuroscience*, *9*(12), 2067–2077. https://doi.org/10.1093/scan/nsu015
Leek, M. R. (2001). Adaptive procedures in psychophysical research. *Perception & Psychophysics*, *63*(8), 1279–1292. https://doi.org/10.3758/BF03194543
Leek, M. R., Brown, M. E., & Dorman, M. F. (1991). Informational masking and auditory attention. *Perception & Psychophysics*, *50*(3), 205–214. https://doi.org/10.3758/bf03206743
Lemus, L., Hernández, A., & Romo, R. (2009). Neural codes for perceptual discrimination of acoustic flutter in the primate auditory cortex. *Proceedings of the National Academy of Sciences*, *106*(23), 9471–9476. https://doi.org/10.1073/pnas.0904066106
Lesmes, L., Lu, Z.-L., Baek, J., Tran, N., Dosher, B., & Albright, T. (2015). Developing Bayesian adaptive methods for estimating sensitivity thresholds (*d'*) in yes-no and forced-choice tasks. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01070
Levey, A. B., & Martin, I. (1975). Classical conditioning of human 'evaluative' responses. *Behaviour Research and Therapy*, *13*(4), 221–226. https://doi.org/10.1016/0005-7967(75)90026-1
Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *The Journal of the Acoustical Society of America*, *49*(2B), 467–477. https://doi.org/10.1121/1.1912375
Licklider, J. C. R. (1951). A duplex theory of pitch perception. *The Journal of the Acoustical Society of America*, *23*(1), 147–147. https://doi.org/10.1121/1.1917296
Licklider, J. C. R. (1954). "Periodicity" pitch and "place" pitch. *The Journal of the Acoustical Society of America*, *26*(5), 945–945. https://doi.org/10.1121/1.1928005
Lin, J.-F. L., Imada, T., Kuhl, P. K., & Lin, F.-H. (2018). Incongruent pitch cues are associated with increased activation and functional connectivity in the frontal areas. *Scientific Reports*, *8*(1), 5206. https://doi.org/10.1038/s41598-018-23287-5
Lindquist, K. A., Wager, T. D., Kober, H., Bliss-Moreau, E., & Barrett, L. F. (2012). The brain basis of emotion: A meta-analytic review. *Behavioral and Brain Sciences*, *35*(3), 121–143. https://doi.org/10.1017/S0140525X11000446
Lipp, O. V., Oughton, N., & LeLievre, J. (2003). Evaluative learning in human Pavlovian conditioning: Extinct, but still there? *Learning and Motivation*, *34*(3), 219–239. https://

doi.org/10.1016/S0023-9690(03)00011-0

Lipp, O. V., & Purkis, H. M. (2005). No support for dual process accounts of human affective learning in simple Pavlovian conditioning. *Cognition & Emotion*, *19*(2), 269–282. https://doi.org/10.1080/02699930441000319

Lipp, O. V., & Purkis, H. M. (2006). The effects of assessment type on verbal ratings of conditional stimulus valence and contingency judgments: Implications for the extinction of evaluative learning. *Journal of Experimental Psychology: Animal Behavior Processes*, *32*(4), 431–440. https://doi.org/10.1037/0097-7403.32.4.431

Lu, T., Liang, L., & Wang, X. (2001). Temporal and rate representations of time-varying signals in the auditory cortex of awake primates. *Nature Neuroscience*, *4*(11), 1131–1138. https://doi.org/10.1038/nn737

Lupyan, G. (2015a). Cognitive penetrability of perception in the age of prediction: Predictive systems are penetrable systems. *Review of Philosophy and Psychology*, *6*(4), 547–569. https://doi.org/10.1007/s13164-015-0253-4

Lupyan, G. (2015b). Reply to Macpherson: Further illustrations of the cognitive penetrability of perception. *Review of Philosophy and Psychology*, *6*(4), 585–589. https://doi.org/10.1007/s1316

Lupyan, G. (2016). Not even wrong: The "it's just X" fallacy. *Behavioral and Brain Sciences*, *39*. https://doi.org/10.1017/S0140525X15002721

Lupyan, G., & Spivey, M. J. (2008). Perceptual processing is facilitated by ascribing meaning to novel stimuli. *Current Biology*, *18*(10), R410–R412. https://doi.org/10.1016/j.cub.2008.02.073

Machery, E. (2015). Cognitive penetrability: A no-progress report. In J. Zeimbekis & A. Raftopoulos (Eds.), *The cognitive penetrability of perception: New philosophical perspectives* (pp. 59–74). New York, NY: Oxford University Press.

MacKinnon, D. P., Krull, J. L., & Lockwood, C. M. (2000). Equivalence of the mediation, confounding and suppression effect. *Prevention Science*, *1*(4), 173–181. https://doi.org/10.1023/A:1026595011371

Macmillan, N. A., & Creelman, C. D. (2005). *Detection theory: A user's guide* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum.

Macpherson, F. (2012). Cognitive penetration of colour experience: Rethinking the issue in light of an indirect mechanism. *Philosophy and Phenomenological Research*, *84*(1), 24–62. https://doi.org/10.1111/j.1933-1592.2010.00481.x

Macpherson, F. (2017). The relationship between cognitive penetration and predictive coding. *Consciousness and Cognition*, *47*, 6–16. https://doi.org/10.1016/j.concog.2016.04.001

Maddox, W. T., & Bohil, C. J. (1998). Base-rate and payoff effects in multidimensional perceptual categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*(6), 1459–1482. https://doi.org/10.1037/0278-7393.24.6.1459

Malmierca, M. S., Anderson, L. A., & Antunes, F. M. (2015). The cortical modulation of stimulus-specific adaptation in the auditory midbrain and thalamus: a potential neuronal correlate for predictive coding. *Frontiers in Systems Neuroscience*, *9*. https://doi.org/10.3389/fnsys.2015.00019

Marchi, F. (2017). Attention and cognitive penetrability: The epistemic consequences of attention as a form of metacognitive regulation. *Consciousness and Cognition*, *47*, 48–62. https://doi.org/10.1016/j.concog.2016.06.014

Maris, E., Stallen, P. J. M., Vermunt, R., & Steensma, H. (2007a). Evaluating noise in social context: the effect of procedural unfairness on noise annoyance judgments. *The*

Journal of the Acoustical Society of America, *122*(6), 3483–3494. https://doi.org/10.1121/1.2799901

Maris, E., Stallen, P. J. M., Vermunt, R., & Steensma, H. (2007b). Noise within the social context: Annoyance reduction through fair procedures. *The Journal of the Acoustical Society of America*, *121*(4), 2000–2010. https://doi.org/10.1121/1.2535507

Markett, S., Weber, B., Voigt, G., Montag, C., Felten, A., Elger, C., & Reuter, M. (2013). Intrinsic connectivity networks and personality: The temperament dimension harm avoidance moderates functional connectivity in the resting brain. *Neuroscience*, *240*, 98–105. https://doi.org/10.1016/j.neuroscience.2013.02.056

Markov, N. T., & Kennedy, H. (2013). The importance of being hierarchical. *Current Opinion in Neurobiology*, *23*(2), 187–194. https://doi.org/10.1016/j.conb.2012.12.008

Markov, N. T., Vezoli, J., Chameau, P., Falchier, A., Quilodran, R., Huissoud, C., … Kennedy, H. (2014). Anatomy of hierarchy: Feedforward and feedback pathways in macaque visual cortex. *Journal of Comparative Neurology*, *522*(1), 225–259. https://doi.org/10.1002/cne.23458

Marks, L. E., & Florentine, M. (2011). Measurement of loudness, part I: Methods, problems, and pitfalls. In M. Florentine, A. N. Popper, & R. R. Fay (Eds.), *Loudness* (pp. 17–56). New York: Springer. https://doi.org/10.1007/978-1-4419-6712-1_2

Marks, L. E., & Gescheider, G. A. (2002). Psychophysical scaling. In *Stevens' handbook of experimental psychology: Methodology in experimental psychology* (3rd ed., Vol. 4, pp. 91–138). Hoboken, NJ: John Wiley & Sons Inc. https://doi.org/10.1002/0471214426.pas0403

Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*. San Francisco, CA: W.H. Freeman.

Marshall, L., Hanna, T. E., & Wilson, R. H. (1996). Effect of step size on clinical and adaptive 2IFC procedures in quiet and in a noise background. *Journal of Speech, Language, and Hearing Research*, *39*(4), 687–696. https://doi.org/10.1044/jshr.3904.687

Marshall, L., & Jesteadt, W. (1986). Comparison of pure-tone audibility thresholds obtained with audiological and two-interval forced-choice procedures. *Journal of Speech, Language, and Hearing Research*, *29*(1), 82–91. https://doi.org/10.1044/jshr.2901.82

Mather, M., & Sutherland, M. R. (2011). Arousal-biased competition in perception and memory. *Perspectives on Psychological Science*, *6*(2), 114–133. https://doi.org/10.1177/1745691611400234

Mayer, J. D., Gaschke, Y. N., Braverman, D. L., & Evans, T. W. (1992). Mood-congruent judgment is a general effect. *Journal of Personality and Social Psychology*, *63*(1), 119–132. https://doi.org/10.1037/0022-3514.63.1.119

McClelland, J. L., Mirman, D., Bolger, D. J., & Khaitan, P. (2014). Interactive activation and mutual constraint satisfaction in perception and cognition. *Cognitive Science*, *38*(6), 1139–1189. https://doi.org/10.1111/cogs.12146

McCrae, R. R. (1993). Openness to experience as a basic dimension of personality. *Imagination, Cognition and Personality*, *13*(1), 39–55. https://doi.org/10.2190/H8H6-QYKR-KEU8-GAQ0

McCrae, R. R., & Costa, P. T. (1987). Validation of the five-factor model of personality across instruments and observers. *Journal of Personality and Social Psychology*, *52*(1), 81–90. https://doi.org/10.1037/0022-3514.52.1.81

McCrae, R. R., & Costa, P. T. (1997). Conceptions and correlates of openness to experience. In R. Hogan, J. A. Johnson, & S. R. Briggs (Eds.), *Handbook of personality psychology* (pp.

825–847). San Diego, CA: Academic Press. https://doi.org/10.1016/B978-012134645-4/50032-9

McCrae, R. R., & Costa, P. T., Jr. (1991). Adding liebe und arbeit: The full five-factor model and well-being. *Personality and Social Psychology Bulletin*, *17*(2), 227–232. https://doi.org/10.1177/0146167291017002177

McCurdy, H. G. (1956). Coin perception studies and the concept of schemata. *Psychological Review*, *63*(3), 160–168. https://doi.org/10.1037/h0046614

McDermott, J. (2018). Audition. In J. T. Wixted & J. Serences (Eds.), *Stevens' handbook of experimental psychology and cognitive neuroscience: Sensation, perception, and attention* (4th ed., Vol. 2, pp. 63–120). New York, NY: Wiley. https://doi.org/10.1002/9781119170174.epcn202

McGinley, M., David, S., & McCormick, D. (2015). Cortical membrane potential signature of optimal states for sensory signal detection. *Neuron*, *87*(1), 179–192. https://doi.org/10.1016/j.neuron.2015.05.038

McNicol, D. (2005). *A primer of signal detection theory*. Mahwah, N.J.: Psychology Press.

McPherson, M. J., & McDermott, J. H. (2018). Diversity in pitch perception revealed by task dependence. *Nature Human Behaviour*, *2*(1), 52–66. https://doi.org/10.1038/s41562-017-0261-8

Meddis, R., & Hewitt, M. J. (1991). Virtual pitch and phase sensitivity of a computer model of the auditory periphery. I: Pitch identification. *The Journal of the Acoustical Society of America*, *89*(6), 2866–2882. https://doi.org/10.1121/1.400725

Meddis, R., & O'Mard, L. (1997). A unitary model of pitch perception. *The Journal of the Acoustical Society of America*, *102*(3), 1811–1820. https://doi.org/10.1121/1.420088

Meier, B. P., & Robinson, M. D. (2004). Why the sunny side is up: Associations between affect and vertical position. *Psychological Science*, *15*(4), 243–247. https://doi.org/10.1111/j.0956-7976.2004.00659.x

Meier, B. P., & Robinson, M. D. (2006). Does "feeling down" mean seeing down? Depressive symptoms and vertical selective attention. *Journal of Research in Personality*, *40*(4), 451–461. https://doi.org/10.1016/j.jrp.2005.03.001

Meier, B. P., Robinson, M. D., Crawford, L. E., & Ahlvers, W. J. (2007). When 'light' and 'dark' thoughts become light and dark responses: Affect biases brightness judgments. *Emotion*, *7*(2), 366–376. https://doi.org/10.1037/1528-3542.7.2.366

Meyer, A. C., & Moser, T. (2010). Structure and function of cochlear afferent innervation. *Current Opinion in Otolaryngology & Head and Neck Surgery*, *18*(5), 441–446. https://doi.org/10.1097/MOO.0b013e32833e0586

Miedema, H. M. E., & Vos, H. (1999). Demographic and attitudinal factors that modify annoyance from transportation noise. *The Journal of the Acoustical Society of America*, *105*(6), 3336–3344. https://doi.org/10.1121/1.424662

Miedema, H. M. E., & Vos, H. (2003). Noise sensitivity and reactions to noise and other environmental conditions. *The Journal of the Acoustical Society of America*, *113*(3), 1492–1504. https://doi.org/10.1121/1.1547437

Mitchell, C. J., Anderson, N. E., & Lovibond, P. F. (2003). Measuring evaluative conditioning using the implicit association test. *Learning and Motivation*, *34*(2), 203–217. https://doi.org/10.1016/S0023-9690(03)00003-1

Mitchell, R. L. C., & Phillips, L. H. (2007). The psychological, neurochemical and functional neuroanatomical mediators of the effects of positive and negative mood on executive functions. *Neuropsychologia*, *45*(4), 617–629. https://doi.org/10.1016/j.neuropsychologia.2006.06.030

Mitchell, R. L. C., & Ross, E. D. (2013). Attitudinal prosody: What we know and directions for future study. *Neuroscience & Biobehavioral Reviews*, *37*(3), 471–479. https://doi.org/10.1016/j.neubiorev.2013.01.027

Miyakita, T., Hellström, P.-A., Frimanson, E., & Axelsson, A. (1992). Effect of low level acoustic stimulation on temporary threshold shift in young humans. *Hearing Research*, *60*(2), 149–155. https://doi.org/10.1016/0378-5955(92)90017-h

Moore, B. C. J. (2003). *An introduction to the psychology of hearing* (5th ed.). London, UK: Elsevier Academic Press.

Moore, B. C. J. (2012). *An introduction to the psychology of hearing* (6th ed.). Bingley, UK: Emerald Group Publishing Limited.

Moors, A., Ellsworth, P. C., Scherer, K. R., & Frijda, N. H. (2013). Appraisal theories of emotion: State of the art and future development. *Emotion Review*, *5*(2), 119–124. https://doi.org/10.1177/1754073912468165

Morgan, M. J., Dillenburger, B., Raphael, S., & Solomon, J. A. (2012). Observers can voluntarily shift their psychometric functions without losing sensitivity. *Attention, Perception, & Psychophysics*, *74*(1), 185–193. https://doi.org/10.3758/s13414-011-0222-7

Morgan, M. J., Melmoth, D., & Solomon, J. A. (2013). Linking hypotheses underlying class A and class B methods. *Visual Neuroscience*, *30*(5-6), 197–206. https://doi.org/10.1017/S095252381300045X

Mõttus, R., Allik, J., Realo, A., Rossier, J., Zecca, G., Ah-Kion, J., ... Johnson, W. (2012). The effect of response style on self-reported conscientiousness across 20 countries. *Personality and Social Psychology Bulletin*, *38*(11), 1423–1436. https://doi.org/10.1177/0146167212451275

Mulders, W. H. A. M., Seluakumaran, K., & Robertson, D. (2008). Effects of centrifugal pathways on responses of cochlear nucleus neurons to signals in noise. *European Journal of Neuroscience*, *27*(3), 702–714. https://doi.org/10.1111/j.1460-9568.2008.06046.x

Murphy, F. C., Sahakian, B. J., Rubinsztein, J. S., Michael, A., Rogers, R. D., Robbins, T. W., & Paykel, E. S. (1999). Emotional bias and inhibitory control processes in mania and depression. *Psychological Medicine*, *29*(6), 1307–1321. https://doi.org/10.1017/S0033291799001233

Murphy, P. R., Robertson, I. H., Balsters, J. H., & O'Connell, R. G. (2011). Pupillometry and P3 index the locus coeruleus-noradrenergic arousal function in humans. *Psychophysiology*, *48*(11), 1532–1543. https://doi.org/10.1111/j.1469-8986.2011.01226.x

Musiek, F. E., & Baran, J. A. (2020). *The auditory system: Anatomy, physiology, and clinical correlates*. San Diego, CA: Plural Publishing.

Narayan, S. S., Temchin, A. N., Recio, A., & Ruggero, M. A. (1998). Frequency tuning of basilar membrane and auditory nerve fibers in the same cochleae. *Science*, *282*(5395), 1882–1884. https://doi.org/10.1126/science.282.5395.1882

Nebylitsyn, V. D., Rozhdestvenskaya, V. I., & Teplov, B. M. (1960). Concerning the interrelation between absolute sensitivity and strength of the nervous system. *Quarterly Journal of Experimental Psychology*, *12*(1), 17–25. https://doi.org/10.1080/17470216008416695

Neuhoff, J. G. (2004). *Ecological psychoacoustics*. Amsterdam: Elsevier Academic Press.

Newen, A., Marchi, F., & Brössel, P. (Eds.). (2017). Cognitive penetration and predictive coding [Special issue]. *Consciousness and Cognition*, *47*, 1–112.

Nieuwenhuis, S., De Geus, E. J., & Aston-Jones, G. (2011). The anatomical and functional relationship between the P3 and autonomic components of the orienting response. *Psychophysiology*, *48*(2), 162–175. https://doi.org/10.1111/j.1469-8986.2010.01057.x

Ninomiya, T., Sawamura, H., Inoue, K.-i., & Takada, M. (2012). Segregated pathways carrying frontally derived top-down signals to visual areas MT and V4 in macaques. *The Journal of Neuroscience*, *32*(20), 6851–6858. https://doi.org/10.1523/jneurosci.6295-11.2012

O'Callaghan, C., Kveraga, K., Shine, J. M., Adams, R. B., Jr., & Bar, M. (2017). Predictions penetrate perception: Converging insights from brain, behaviour and disorder. *Consciousness and Cognition*, *47*, 63–74. https://doi.org/10.1016/j.concog.2016.05.003

Ochsner, K. N., & Gross, J. J. (2008). Cognitive emotion regulation: Insights from social cognitive and affective neuroscience. *Current Directions in Psychological Science*, *17*(2), 153–158. https://doi.org/10.1111/j.1467-8721.2008.00566.x

Odgaard, E. C., Arieh, Y., & Marks, L. E. (2003). Cross-modal enhancement of perceived brightness: Sensory interaction versus response bias. *Perception & psychophysics*, *65*(1), 123–132. https://doi.org/10.3758/BF03194789

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychological Review*, *108*(3), 483–522. https://doi.org/10.1037/0033-295X.108.3.483

Olson, E. S., Duifhuis, H., & Steele, C. R. (2012). Von Békésy and cochlear mechanics. *Hearing Research*, *293*(1), 31–43. https://doi.org/10.1016/j.heares.2012.04.017

Ormel, J., Oldehinkel, A., Ferdinand, R., Hartman, C., De Winter, A., Veenstra, R., ... Verhulst, F. (2005). Internalizing and externalizing problems in adolescence: General and dimension-specific effects of familial loadings and preadolescent temperament traits. *Psychological Medicine*, *35*(12), 1825–1835. https://doi.org/10.1017/S0033291705005829

Orne, M. T. (1962). On the social psychology of the psychological experiment: With particular reference to demand characteristics and their implications. *American Psychologist*, *17*(11), 776–783. https://doi.org/10.1037/h0043424

Osgood, C. E., May, W. H., & Miron, M. S. (1975). *Cross-cultural universals of affective meaning*. Urbana, IL: University of Illinois Press.

Owren, M. J., & Bachorowski, J. (2007). Measuring emotion-related vocal acoustics. In J. Coan & J. B. Allen (Eds.), *Handbook of emotion elicitation and assessment* (pp. 239–266). New York: Oxford University Press.

Oxenham, A. J. (2013a). Mechanisms and mechanics of auditory masking. *The Journal of Physiology*, *591*(10), 2375–2375. https://doi.org/10.1113/jphysiol.2013.254490

Oxenham, A. J. (2013b). Revisiting place and temporal theories of pitch. *Acoustical Science and Technology*, *34*(6), 388–396. https://doi.org/10.1250/ast.34.388]

Oxenham, A. J., Fligor, B. J., Mason, C. R., & Kidd, G., Jr. (2003). Informational masking and musical training. *The Journal of the Acoustical Society of America*, *114*(3), 1543–1549. https://doi.org/10.1121/1.1598197

Panksepp, J. (1998). *Affective neuroscience: The foundations of human and animal emotions*. New York, NY: Oxford University Press.

Panksepp, J., & Watt, D. (2011). What is basic about basic emotions? Lasting lessons from affective neuroscience. *Emotion Review*, *3*(4), 387–396. https://doi.org/10.1177/1754073911410741

Passchier-Vermeer, W., & Passchier, W. F. (2000). Noise exposure and public health. *Environmental Health Perspectives*, *108*(Suppl. 1), 123–131. https://doi.org/10.1289/ehp.00108s1123

Paulhus, D. L. (1991). Measurement and control of response bias. In J. Robinson, P. Shaver, & L. Wrightsman (Eds.), *Measures of personality and social psychological attitudes* (pp. 17–59). San Diego, CA: Academic Press.

Paulhus, D. L., & Levitt, K. (1987). Desirable responding triggered by affect: Automatic egotism? *Journal of Personality and Social Psychology*, *52*(2), 245–259. https://doi.org/10.1037/0022-3514.52.2.245

Paulhus, D. L., & Lim, D. T. K. (1994). Arousal and evaluative extremity in social judgments: A dynamic complexity model. *European Journal of Social Psychology*, *24*(1), 89–99. https://doi.org/10.1002/ejsp.2420240107

Pessoa, L. (2008). On the relationship between emotion and cognition. *Nature Reviews Neuroscience*, *9*(2), 148–158. https://doi.org/10.1038/nrn2317

Pessoa, L. (2014). Understanding brain networks and brain organization. *Physics of Life Reviews*, *11*(3), 400–435. https://doi.org/10.1016/j.plrev.2014.03.005

Phelps, E. A., Ling, S., & Carrasco, M. (2006). Emotion facilitates perception and potentiates the perceptual benefits of attention. *Psychological Science*, *17*(4), 292–299. https://doi.org/10.1111/j.1467-9280.2006.01701.x

Philbeck, J. W., & Witt, J. K. (2015). Action-specific influences on perception and postperceptual processes: Present controversies and future directions. *Psychological Bulletin*, *141*(6), 1120–1144. https://doi.org/10.1037/a0039738

Pickering, A. D., & Gray, J. A. (1999). The neuroscience of personality. In L. A. Pervin & O. P. John (Eds.), *Handbook of personality: Theory and research* (Vol. 2, pp. 277–299). New York, NY: The Guilford Press.

Plack, C., & Oxenham, A. (2005a). Overview: The present and future of pitch. In C. Plack, R. Fay, A. Oxenham, & A. Popper (Eds.), *Pitch: Neural coding and perception* (pp. 1–6). New York, NY: Springer.

Plack, C., & Oxenham, A. (2005b). The psychophysics of pitch. In C. Plack, R. Fay, A. Oxenham, & A. Popper (Eds.), *Pitch: Neural coding and perception* (pp. 7–55). New York, NY: Springer.

Plomp, R. (1967). Pitch of complex tones. *The Journal of the Acoustical Society of America*, *41*(6), 1526–1533. https://doi.org/10.1121/1.1910515

Pollack, I. (1969). Periodicity pitch for interrupted white noise-fact or artifact? *The Journal of the Acoustical Society of America*, *45*(1), 237–238. https://doi.org/10.1121/1.1911363

Pollack, I. (1975). Auditory informational masking. *The Journal of the Acoustical Society of America*, *57*(S1), S5–S5. https://doi.org/10.1121/1.1995329

Poulton, E. C. (1979). Models for biases in judging sensory magnitude. *Psychological Bulletin*, *86*(4), 777–803. https://doi.org/10.1037/0033-2909.86.4.777

Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological correlates of rapid spatial orienting towards fearful faces. *Cerebral Cortex*, *14*(6), 619–633. https://doi.org/10.1093/cercor/bhh023

Pressnitzer, D., Graves, J., Chambers, C., de Gardelle, V., & Egré, P. (2018). Auditory perception: Laurel and Yanny together at last. *Current Biology*, *28*(13), R739–R741. https://doi.org/10.1016/j.cub.2018.06.002

Pylyshyn, Z. W. (1980). Computation and cognition: issues in the foundations of cognitive science. *Behavioral and Brain Sciences*, *3*(1), 111–132. https://doi.org/10.1017/S0140525X00002053

Pylyshyn, Z. W. (1984). *Computation and cognition: Toward a foundation for cognitive science*. Cambridge, MA: The MIT Press.

Pylyshyn, Z. W. (1999). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, *22*(3), 341–365. https://doi.org/10.1017/S0140525X99002022

Quirin, M., Kent, M., Boksem, M. A. S., & Tops, M. (2015). Integration of negative experiences: A neuropsychological framework for human resilience. *Behavioral and Brain Sciences*, *38*. https://doi.org/10.1017/S0140525X14001666

Rabinowitz, N. C., Willmore, B. D. B., Schnupp, J. W. H., & King, A. J. (2011). Contrast gain control in auditory cortex. *Neuron*, *70*(6), 1178–1191. https://doi.org/10.1016/j.neuron.2011.04.030

Raftopoulos, A. (2001). Is perception informationally encapsulated? the issue of the theory-ladenness of perception. *Cognitive Science*, *25*(3), 423–451. https://doi.org/10.1207/s15516709cog2503_4

Raftopoulos, A. (2009). *Cognition and perception: How do psychology and neural science inform philosophy?* Cambridge, MA: Mit Press.

Raftopoulos, A. (2014). Does the emotional modulation of visual experience entail the cognitive penetrability or emotional penetrability of early vision? *Proceedings of the Annual Meeting of the Cognitive Science Society*, *36*, 1216–1221. Retrieved from https://escholarship.org/uc/item/0j97t3dt

Raftopoulos, A. (2016). Studies on cognitively driven attention suggest that late vision is cognitively penetrated, whereas early vision is not. *Behavioral and Brain Sciences*, *39*. https://doi.org/10.1017/S0140525X15002484

Rahnev, D., & Denison, R. N. (2018). Suboptimality in perceptual decision making. *Behavioral and Brain Sciences*, *41*. https://doi.org/10.1017/S0140525X18000936

Rammsayer, T. H., & Troche, S. J. (2012). On sex-related differences in auditory and visual sensory functioning. *Archives of Sexual Behavior*, *41*(3), 583–590. https://doi.org/10.1007/s10508-011-9880-8

Rao, R. P. N., & Ballard, D. H. (1999). Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive-field effects. *Nature Neuroscience*, *2*(1), 79–87. https://doi.org/10.1038/4580

Rauss, K., Schwartz, S., & Pourtois, G. (2011). Top-down effects on early visual processing in humans: A predictive coding framework. *Neuroscience & Biobehavioral Reviews*, *35*(5), 1237–1253. https://doi.org/10.1016/j.neubiorev.2010.12.011

Recio-Spinoso, A., & Cooper, N. P. (2013). Masking of sounds by a background noise – cochlear mechanical correlates. *The Journal of Physiology*, *591*(10), 2705–2721. https://doi.org/10.1113/jphysiol.2012.248260

Riener, C. R., Stefanucci, J. K., Proffitt, D. R., & Clore, G. (2011). An effect of mood on the perception of geographical slant. *Cognition & Emotion*, *25*(1), 174–182. https://doi.org/10.1080/02699931003738026

Robertson, D., & Manley, G. A. (1974). Manipulation of frequency analysis in the cochlear ganglion of the guinea pig. *Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology*, *91*(4), 363–375. https://doi.org/10.1007/BF00694467

Robinson, B. L., & McAlpine, D. (2009). Gain control mechanisms in the auditory pathway. *Current Opinion in Neurobiology*, *19*(4), 402–407. https://doi.org/10.1016/j.conb.2009.07.006

Robinson, D. (1988). Threshold of hearing as a function of age and sex for the typical unscreened population. *British Journal of Audiology*, *22*(1), 5–20. https://doi.org/10.3109/03005368809077793

Romo, R., & de Lafuente, V. (2013). Conversion of sensory signals into perceptual decisions. *Progress in Neurobiology*, *103*, 41–75. https://doi.org/10.1016/j.pneurobio.2012.03.007

Romo, R., & Salinas, E. (2003). Flutter discrimination: neural codes, perception, memory and decision making. *Nature Reviews Neuroscience*, *4*(3), 203–218. https://doi.org/10.1038/nrn1058

Rose, J. E., Brugge, J. F., Anderson, D. J., & Hind, J. E. (1967). Phase-locked response to low-frequency tones in single auditory nerve fibers of the squirrel monkey. *Journal of Neurophysiology*, *30*(4), 769–793. https://doi.org/10.1152/jn.1967.30.4.769

Rowe, G., Hirsh, J. B., & Anderson, A. K. (2007). Positive affect increases the breadth of attentional selection. *Proceedings of the National Academy of Sciences*, *104*(1), 383–388. https://doi.org/10.1073/pnas.0605198104

Rozin, P., & Millman, L. (1987). Family environment, not heredity, accounts for family resemblances in food preferences and attitudes: A twin study. *Appetite*, *8*(2), 125–134. https://doi.org/10.1016/S0195-6663(87)80005-3

Rozin, P., & Royzman, E. B. (2001). Negativity bias, negativity dominance, and contagion. *Personality and Social Psychology Review*, *5*(4), 296–320. https://doi.org/10.1207/s15327957pspr0504_2

Russ, B. E., Orr, L. E., & Cohen, Y. E. (2008). Prefrontal neurons predict choices during an auditory same-different task. *Current Biology*, *18*(19), 1483–1488. https://doi.org/10.1016/j.cub.2008.08.054

Russell, I. J., & Sellick, P. M. (1977). Tuning properties of cochlear hair cells. *Nature*, *267*(5614), 858–860. https://doi.org/10.1038/267858a0

Russell, J. A. (1989). Affect grid: A single-item scale of pleasure and arousal. *Journal of Personality and Social Psychology*, *57*(3), 493–502. https://doi.org/10.1037/0022-3514.57.3.493.

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review*, *110*(1), 145–172. https://doi.org/10.1037/0033-295x.110.1.145

Russell, J. A. (2009). Emotion, core affect, and psychological construction. *Cognition and Emotion*, *23*(7), 1259–1283. https://doi.org/10.1080/02699930902809375

Russell, J. A., & Barrett, L. F. (1999). Core affect, prototypical emotional episodes, and other things called emotion: Dissecting the elephant. *Journal of Personality and Social Psychology*, *76*(5), 805–819. https://doi.org/10.1037/0022-3514.76.5.805

Russell, J. A., & Carroll, J. M. (1999). On the bipolarity of positive and negative affect. *Psychological Bulletin*, *125*(1), 3–30. Retrieved from 10.1037/0033-2909.125.1.3http://search.ebscohost.com/login.aspx?direct=true&db=pdh&AN=bul-125-1-3&site=ehost-live

Russell, J. A., & Mehrabian, A. (1977). Evidence for a three-factor theory of emotions. *Journal of Research in Personality*, *11*(3), 273–294. https://doi.org/10.1016/0092-6566(77)90037-X

Russell, J. A., & Pratt, G. (1980). A description of the affective quality attributed to environments. *Journal of Personality and Social Psychology*, *38*(2), 311–322. https://doi.org/10.1037/0022-3514.38.2.311

Russell, J. A., Weiss, A., & Mendelsohn, G. A. (1989). Affect grid: A single-item scale of pleasure and arousal. *Journal of Personality and Social Psychology*, *57*(3), 493–502. https://doi.org/10.1037/0022-3514.57.3.493

Saenz, M., & Langers, D. R. M. (2014). Tonotopic mapping of human auditory cortex. *Hearing Research*, *307*, 42–52. https://doi.org/10.1016/j.heares.2013.07.016

Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social Science Information*, *44*(4), 695–729. https://doi.org/10.1177/0539018405058216

Scherer, K. R. (2009). Emotion theories and concepts (psychological perspectives). In D. Sander & K. R. Scherer (Eds.), *The Oxford companion to emotion and the affective sciences* (pp. 145–149). New York, NY: Oxford University Press.

Scherer, K. R., & Zentner, M. R. (2001). Emotional effects of music: Production rules. In P. Juslin & J. Sloboda (Eds.), *Music and emotion: Theory and research.* (pp. 361–392). New York, NY: Oxford University Press.

Scherer, L. D., & Larsen, R. J. (2011). Cross-modal evaluative priming: Emotional sounds influence the processing of emotion words. *Emotion*, *11*(1), 203–208. https://doi.org/10.1037/a0022588

Schnall, S. (2017). No magic bullet in sight: A reply to Firestone and Scholl (2017) and Durgin (2017). *Perspectives on Psychological Science*, *12*(2), 347–349. https://doi.org/10.1177/1745691617691948

Schneider, P., Sluming, V., Roberts, N., Scherg, M., Goebel, R., Specht, H. J., … Rupp, A. (2005). Structural and functional asymmetry of lateral Heschl's gyrus reflects pitch perception preference. *Nature Neuroscience*, *8*(9), 1241–1247. https://doi.org/10.1038/nn1530

Schneider, P., & Wengenroth, M. (2009). The neural basis of individual holistic and spectral sound perception. *Contemporary Music Review*, *28*(3), 315–328. https://doi.org/10.1080/07494460903404402

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-prime user's guide.* Pittsburgh, PA: Psychology Software Tools Inc.

Schouten, J. F. (1938). The perception of subjective tones. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen*, *41*, 1086–1093.

Schouten, J. F. (1940). The residue, a new component in subjective sound analysis. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen*, *43*, 356–365.

Schouten, J. F. (1970). The residue revisited. In R. Plomp & G. F. Smoorenburg (Eds.), *Frequency analysis and periodicity detection in hearing* (pp. 41–58). Leiden, The Netherlands: Sijthoff.

Schouten, J. F., Ritsma, R. J., & Cardozo, B. L. (1962). Pitch of the residue. *The Journal of the Acoustical Society of America*, *34*(9B), 1418–1424. https://doi.org/10.1121/1.1918360

Schwarz, N., & Clore, G. L. (1983). Mood, misattribution, and judgments of well-being: Informative and directive functions of affective states. *Journal of Personality and Social Psychology*, *45*(3), 513–523. https://doi.org/10.1037/0022-3514.45.3.513

Schwarz, N., & Clore, G. L. (2007). Feelings and phenomenal experiences. In A. Kruglanski & E. Higgins (Eds.), *Social psychology: Handbook of basic principles* (pp. 385–407). New York: Guilford.

Seebeck, A. (1841). Beobachtungen über einige bedingungen der entstehung von tönen. *Annalen der Physik*, *129*(7), 417–436. https://doi.org/10.1002/andp.18411290702

Seeley, W. W., Menon, V., Schatzberg, A. F., Keller, J., Glover, G. H., Kenna, H., … Greicius, M. D. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *The Journal of Neuroscience*, *27*(9), 2349–2356. https://doi.org/10.1523/jneurosci.5587-06.2007

Seifritz, E., Esposito, F., Neuhoff, J. G., Lüthi, A., Mustovic, H., Dammann, G., … Di Salle, F. (2003). Differential sex-independent amygdala response to infant crying and laughing in parents versus nonparents. *Biological Psychiatry*, *54*(12), 1367–1375. https://doi.org/10.1016/S0006-3223(03)00697-8

Seither-Preisler, A., Johnson, L., Krumbholz, K., Nobbe, A., Patterson, R., Seither, S., & Lütkenhöner, B. (2007). Tone sequences with conflicting fundamental pitch and timbre changes are heard differently by musicians and nonmusicians. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(3), 743–751. https://doi.org/10.1037/0096-1523.33.3.743

Seluakumaran, K., Mulders, W. H. A. M., & Robertson, D. (2008). Unmasking effects of olivocochlear efferent activation on responses of inferior colliculus neurons. *Hearing Research*, *243*(1-2), 35–46. https://doi.org/10.1016/j.heares.2008.05.004

Servan-Schreiber, D., Printz, H., & Cohen, J. D. (1990). A network model of catecholamine effects: gain, signal-to-noise ratio, and behavior. *Science*, *249*(4971), 892–895. https://doi.org/10.1126/science.2392679

Shackleton, T. M., & Carlyon, R. P. (1994). The role of resolved and unresolved harmonics in pitch perception and frequency modulation discrimination. *The Journal of the Acoustical Society of America*, *95*(6), 3529–3540. https://doi.org/10.1121/1.409970

Siddle, D. A., Morrish, R. B., White, K. D., & Mangan, G. L. (1969). Relation of visual sensitivity to extraversion. *Journal of Experimental Research in Personality*, *3*(4), 264–267.

Siegel, E. H., & Stefanucci, J. K. (2011). A little bit louder now: Negative affect increases perceived loudness. *Emotion*, *11*(4), 1006–1011. https://doi.org/10.1037/a0024590

Siegel, E. H., Wormwood, J. B., Quigley, K. S., & Barrett, L. F. (2018). Seeing what you feel: Affect drives visual perception of structurally neutral faces. *Psychological Science*, *29*(4), 496–503. https://doi.org/10.1177/0956797617741718

Siegel, R. J. (1965). A replication of the mel scale of pitch. *The American Journal of Psychology*, *78*(4), 615–620. https://doi.org/10.2307/1420924

Siegel, S., & Silins, N. (2014). The epistemology of perception. In M. Matthen (Ed.), *The Oxford handbook of philosophy of perception.* doi: 10.1093/oxfordhb/9780199600472.013.040. https://doi.org/10.1093/oxfordhb/9780199600472.013.040

Siemer, M. (2001). Mood-specific effects on appraisal and emotion judgements. *Cognition and Emotion*, *15*(4), 453–485. https://doi.org/10.1080/02699930126083

Simonsohn, U. (2015). Small telescopes: Detectability and the evaluation of replication results. *Psychological Science*, *26*(5), 559–569. https://doi.org/10.1177/0956797614567341

Slee, S. J., & David, S. V. (2015). Rapid task-related plasticity of spectrotemporal receptive fields in the auditory midbrain. *The Journal of Neuroscience*, *35*(38), 13090–13102. https://doi.org/10.1523/jneurosci.1671-15.2015

Slepian, M. L., & Ambady, N. (2014). Simulating sensorimotor metaphors: Novel metaphors influence sensory judgments. *Cognition*, *130*(3), 309–314. https://doi.org/10.1016/j.cognition.2013.11.006

Smith, D. W., Aouad, R., & Keil, A. (2012). Cognitive task demands modulate the sensitivity of the human cochlea. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00030

Smith, D. W., & Keil, A. (2015). The biological role of the medial olivocochlear efferents in hearing: Separating evolved function from exaptation. *Frontiers in Systems Neuroscience*, *9*. https://doi.org/10.3389/fnsys.2015.00012

Smith, S. L. (1968). Extraversion and sensory threshold. *Psychophysiology*, *5*(3), 293–299. https://doi.org/10.1111/j.1469-8986.1968.tb02825.x

Smoorenburg, G. F. (1970). Pitch perception of two-frequency stimuli. *Journal of the Acoustical Society of America*, *48*(4B), 924–942. https://doi.org/10.1121/1.1912232

Stallen, P. J. M. (1999). A theoretical framework for environmental noise annoyance. *Noise and Health*, *1*(3), 69–79. Retrieved from http://www.noiseandhealth.org/article.asp?issn=1463-1741;year=1999;volume=1;issue=3;spage=69;epage=79;aulast=Stallen

Stefanucci, J. K., Gagnon, K. T., & Lessard, D. A. (2011). Follow your heart: Emotion adaptively influences perception. *Social and Personality Psychology Compass*, *5*(6), 296–308. https://doi.org/10.1111/j.1751-9004.2011.00352.x

Stefanucci, J. K., & Proffitt, D. R. (2009). The roles of altitude and fear in the perception of height. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(2),

424–438. https://doi.org/10.1037/a0013894
Stefanucci, J. K., & Storbeck, J. (2009). Don’t look down: Emotional arousal elevates height perception. *Journal of Experimental Psychology: General*, *138*(1), 131–145. https://doi.org/10.1037/a0014797
Sterzer, P., & Kleinschmidt, A. (2010). Anterior insula activations in perceptual paradigms: Often observed but barely understood. *Brain Structure and Function*, *214*(5), 611–622. https://doi.org/10.1007/s00429-010-0252-2
Stevens, S. S., Volkmann, J., & Newman, E. B. (1937). A scale for the measurement of the psychological magnitude pitch. *The Journal of the Acoustical Society of America*, *8*(3), 185–190. https://doi.org/10.1121/1.1915893
Stokes, D. (2013). Cognitive penetrability of perception. *Philosophy Compass*, *8*(7), 646–663. https://doi.org/10.1111/phc3.12043
Stokes, D. (2018). Attention and the cognitive penetrability of perception. *Australasian Journal of Philosophy*, *96*(2), 303–318. https://doi.org/10.1080/00048402.2017.1332080
Stolarova, M., Keil, A., & Moratti, S. (2006). Modulation of the C1 visual event-related component by conditioned stimuli: Evidence for sensory plasticity in early affective perception. *Cerebral Cortex*, *16*(6), 876–887. https://doi.org/10.1093/cercor/bhj031
Storrs, K. R. (2015). Are high-level aftereffects perceptual? *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.00157
Strait, D. L., Kraus, N., Parbery-Clark, A., & Ashley, R. (2010). Musical experience shapes top-down auditory mechanisms: Evidence from masking and auditory attention performance. *Hearing Research*, *261*(1-2), 22–29. https://doi.org/10.1016/j.heares.2009.12.021
Stüttgen, M., Schwarz, C., & Jäkel, F. (2011). Mapping spikes to sensations. *Frontiers in Neuroscience*, *5*. https://doi.org/10.3389/fnins.2011.00125
Swets, J. A. (1959). Indices of signal detectability obtained with various psychophysical procedures. *The Journal of the Acoustical Society of America*, *31*(4), 511–513. https://doi.org/10.1121/1.1907744
Swets, J. A., Tanner, W. P., Jr., & Birdsall, T. G. (1961). Decision processes in perception. *Psychological Review*, *68*(5), 301–340. https://doi.org/10.1037/h0040547
Tamir, M., & Robinson, M. D. (2007). The happy spotlight: Positive mood and selective attention to rewarding information. *Personality and Social Psychology Bulletin*, *33*(8), 1124–1136. https://doi.org/10.1177/0146167207301030
Tan, M. N., Robertson, D., & Hammond, G. R. (2008). Separate contributions of enhanced and suppressed sensitivity to the auditory attentional filter. *Hearing Research*, *241*(1-2), 18–25. https://doi.org/10.1016/j.heares.2008.04.003
Tasaki, I. (1954). Nerve impulses in individual auditory nerve fibers of guinea pig. *Journal of Neurophysiology*, *17*(2), 97–122. https://doi.org/10.1152/jn.1954.17.2.97
Teige-Mocigemba, S., & Klauer, K. C. (2008). ‘Automatic’ evaluation? Strategic effects on affective priming. *Journal of Experimental Social Psychology*, *44*(5), 1414–1417. https://doi.org/10.1016/j.jesp.2008.04.004
Terhardt, E. (1974). Pitch, consonance, and harmony. *The Journal of the Acoustical Society of America*, *55*(5), 1061–1069. https://doi.org/10.1121/1.1914648
Terreros, G., & Delano, P. H. (2015). Corticofugal modulation of peripheral auditory responses. *Frontiers in Systems Neuroscience*, *9*. https://doi.org/10.3389/fnsys.2015.00134
Teufel, C., & Nanay, B. (2017). How to (and how not to) think about top-down influences on visual perception. *Consciousness and Cognition*, *47*, 17–25. https://doi.org/10.1016/j.concog.2016.05.008

Thayer, R. E. (1996). *The origin of everyday moods: Managing energy, tension, and stress*. New York, NY: Oxford University Press.

Thurlow, W. R., & Rawlings, I. L. (1959). Recognition thresholds for simple tonal patterns. *Perceptual and Motor Skills*, *9*(2), 295–301. https://doi.org/10.2466/pms.1959.9.h.295

Tops, M., & Boksem, M. A. S. (2010). Absorbed in the task: Personality measures predict engagement during task performance as tracked by error negativity and asymmetrical frontal activity. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(4), 441–453. https://doi.org/10.3758/cabn.10.4.441

Tops, M., & Boksem, M. A. S. (2012). "What's that?" "What went wrong?" positive and negative surprise and the rostral-ventral to caudal-dorsal functional gradient in the brain. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00021

Tops, M., Boksem, M. A. S., Luu, P., & Tucker, D. M. (2010). Brain substrates of behavioral programs associated with self-regulation. *Frontiers in Psychology*, *1*. https://doi.org/10.3389/fpsyg.2010.00152

Tops, M., Boksem, M. A. S., Quirin, M., IJzerman, H., & Koole, S. L. (2014). Internally directed cognition and mindfulness: an integrative perspective derived from predictive and reactive control systems theory. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00429

Tops, M., & Matsumoto, H. (2011). Hypocortisolism is related to environmental stimulus processing sensitivity and psychosomatic complaints. *Psychophysiology*, *48(Suppl. 1)*, S88. https://doi.org/10.1111/j.1469-8986.2011.01259.x

Tops, M., Montero-Marín, J., & Quirin, M. (2016). Too much of a good thing: A neuro-dynamic personality model explaining engagement and its protective inhibition. In S. Kim, J. Reeve, & M. Bong (Eds.), *Advances in motivation and achievement: Vol 19. Recent developments in neuroscience research on human motivation* (pp. 283–319). Bingley, UK: Emerald Group Publishing Limited. https://doi.org/10.1108/S0749-742320160000019012

Totah, N. K. B., Logothetis, N. K., & Eschenko, O. (2019). Noradrenergic ensemble-based modulation of cognition over multiple timescales. *Brain Research*, *1709*, 50–66. https://doi.org/10.1016/j.brainres.2018.12.031

Tsunada, J., Liu, A. S. K., Gold, J. I., & Cohen, Y. E. (2016). Causal contribution of primate auditory cortex to auditory perceptual decision-making. *Nature Neuroscience*, *19*, 135–142. https://doi.org/10.1038/nn.4195

Usher, M., Cohen, J. D., Servan-Schreiber, D., Rajkowski, J., & Aston-Jones, G. (1999). The role of locus coeruleus in the regulation of cognitive performance. *Science*, *283*(5401), 549–554. https://doi.org/10.1126/science.283.5401.549

Vance, J., & Stokes, D. (2017). Noise, uncertainty, and interest: Predictive coding and cognitive penetration. *Consciousness and Cognition*, *47*, 86–98. https://doi.org/10.1016/j.concog.2016.06.007

van Kamp, I., Job, R. F. S., Hatfield, J., Haines, M., Stellato, R. K., & Stansfeld, S. A. (2004). The role of noise sensitivity in the noise-response relation: A comparison of three international airport studies. *The Journal of the Acoustical Society of America*, *116*(6), 3471–3479. https://doi.org/10.1121/1.1810291

van Steenbergen, H., Band, G. P., & Hommel, B. (2010). In the mood for adaptation: How affect regulates conflict-driven control. *Psychological Science*, *21*(11), 1629–1634. https://doi.org/10.1177/0956797610385951

van Tol, M.-J., Veer, I. M., van der Wee, N. J. A., Aleman, A., van Buchem, M. A., Rombouts, S. A. R. B., … Johnstone, T. (2013). Whole-brain functional connectivity during emotional word classification in medication-free major depressive disorder: Abnormal salience circuitry and relations to positive emotionality. *NeuroImage: Clinical*, *2*, 790–796. https://doi.org/10.1016/j.nicl.2013.05.012

Van Vaerenbergh, Y., & Thomas, T. D. (2013). Response styles in survey research: A literature review of antecedents, consequences, and remedies. *International Journal of Public Opinion Research*, *25*(2), 195–217. https://doi.org/10.1093/ijpor/eds021

van Wouwe, N. C., Band, G. P. H., & Ridderinkhof, K. R. (2009). Positive affect modulates flexibility and evaluative control. *Journal of Cognitive Neuroscience*, *23*(3), 524–539. https://doi.org/10.1162/jocn.2009.21380

Västfjäll, D. (2001). Emotion induction through music: A review of the musical mood induction procedure. *Musicae Scientiae*, *5*(Suppl. 1), 173–211. https://doi.org/10.1177/10298649020050s107

Västfjäll, D. (2002). Influences of current mood and noise sensitivity on judgments of noise annoyance. *The Journal of Psychology*, *136*(4), 357. https://doi.org/10.1080/00223980209604163

Västfjäll, D., Kleiner, M., & Gärling, T. (2003). Affective reactions to interior aircraft sounds. *Acta Acustica united with Acustica*, *89*(4), 693–701. Retrieved from https://www.ingentaconnect.com/content/dav/aaua/2003/00000089/00000004/art00014

Västfjäll, D., Slovic, P., Burns, W. J., Erlandsson, A., Koppel, L., Asutay, E., & Tinghög, G. (2016). The arithmetic of emotion: Integration of incidental and integral affect in judgments and decisions. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.00325

von Békésy, G. (1980). *Experiments in hearing* (E. G. Wever, ed., Trans.). Huntington, NY: Robert E. Krieger Publishing Company (Original work published in 1960).

Voss, A., Rothermund, K., & Brandtstädter, J. (2008). Interpreting ambiguous stimuli: Separating perceptual and judgmental biases. *Journal of Experimental Social Psychology*, *44*(4), 1048–1056. https://doi.org/doi.org/10.1016/j.jesp.2007.10.009

Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, *9*(12), 585–594. https://doi.org/10.1016/j.tics.2005.10.011

Walker, K. M. M., Bizley, J. K., King, A. J., & Schnupp, J. W. H. (2011). Cortical encoding of pitch: Recent results and open questions. *Hearing Research*, *271*(1-2), 74–87. https://doi.org/10.1016/j.heares.2010.04.015

Wallace, M. N., Shackleton, T. M., & Palmer, A. R. (2002). Phase-locked responses to pure tones in the primary auditory cortex. *Hearing Research*, *172*(1), 160–171. https://doi.org/10.1016/S0378-5955(02)00580-4

Wang, X. (2013). The harmonic organization of auditory cortex. *Frontiers in Systems Neuroscience*, *7*. https://doi.org/10.3389/fnsys.2013.00114

Wang, X., & Bendor, D. (2010). Pitch. In A. R. Palmer & A. Rees (Eds.), *The Oxford handbook of auditory science: The auditory brain* (pp. 149–172). New York, NY: Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199233281.013.0007

Wang, X., Lu, T., Bendor, D., & Bartlett, E. (2008). Neural coding of temporal information in auditory thalamus and cortex. *Neuroscience*, *154*(1), 294–303. https://doi.org/10.1016/j.neuroscience.2008.03.065

Watson, C. S. (2005). Some comments on informational masking. *Acta Acustica united with Acustica*, *91*(3), 502–512. Retrieved from https://www.ingentaconnect.com/content/dav/aaua/2005/00000091/00000003/art00012

Watson, C. S., Kelly, W. J., & Wroton, H. W. (1976). Factors in the discrimination of tonal patterns. II. Selective attention and learning under various levels of stimulus uncertainty.

The Journal of the Acoustical Society of America, *60*(5), 1176–1186. https://doi.org/10.1121/1.381220

Watson, D., & Tellegen, A. (1985). Toward a consensual structure of mood. *Psychological Bulletin*, *98*(2), 219–235. https://doi.org/10.1037/0033-2909.98.2.219

Weger, U. W., Meier, B. P., Robinson, M. D., & Inhoff, A. W. (2007). Things are sounding up: Affective influences on auditory tone perception. *Psychonomic Bulletin & Review*, *14*(3), 517–521. https://doi.org/10.3758/bf03194100

Weisz, N., Kostadinov, B., Dohrmann, K., Hartmann, T., & Schlee, W. (2007). Tracking short-term auditory cortical plasticity during classical conditioning using frequency-tagged stimuli. *Cerebral Cortex*, *17*(8), 1867–1876. https://doi.org/10.1093/cercor/bhl095

Wever, E. G., & Bray, C. W. (1930). Present possibilities for auditory theory. *Psychological Review*, *37*(5), 365–380. https://doi.org/10.1037/h0075002

Wiethoff, S., Wildgruber, D., Kreifelts, B., Becker, H., Herbert, C., Grodd, W., & Ethofer, T. (2008). Cerebral processing of emotional prosody–influence of acoustic parameters and arousal. *NeuroImage*, *39*(2), 885–893. https://doi.org/10.1016/j.neuroimage.2007.09.028

Wilson, J. P., & Johnstone, J. R. (1975). Basilar membrane and middle-ear vibration in guinea pig measured by capacitive probe. *The Journal of the Acoustical Society of America*, *57*(3), 705–723. https://doi.org/10.1121/1.380472

Wilson-Mendenhall, C. D., Barrett, L. F., & Barsalou, L. W. (2013). Situating emotional experience. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00764

Wiltink, J., Vogelsang, U., & Beutel, M. E. (2006). Temperament and personality: the German version of the Adult Temperament Questionnaire (ATQ). *GMS Psycho-Social Medicine*, *3*(Doc10), 1–10. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2736500/

Wispelwey, P. (2012, September 9). [Video]. Interview by Matthijs van Nieuwkerk. *De Wereld Draait Door* [Video]. Retrieved from http://dewerelddraaitdoor.vara.nl/media/185377

Witt, J. K., Taylor, J. E. T., Sugovic, M., & Wixted, J. T. (2015). Signal detection measures cannot distinguish perceptual biases from response biases. *Perception*, *44*(3), 289–300. https://doi.org/10.1068/p7908

Witteman, J., Van Heuven, V. J. P., & Schiller, N. O. (2012). Hearing feelings: A quantitative meta-analysis on the neuroimaging literature of emotional prosody perception. *Neuropsychologia*, *50*(12), 2752–2763. https://doi.org/10.1016/j.neuropsychologia.2012.07.026

Witthöft, M., Rist, F., & Bailer, J. (2008). Evidence for a specific link between the personality trait of absorption and idiopathic environmental intolerance. *Journal of Toxicology and Environmental Health, Part A*, *71*(11-12), 795–802. https://doi.org/10.1080/15287390801985687

Witzel, C., Valkova, H., Hansen, T., & Gegenfurtner, K. R. (2011). Object knowledge modulates colour appearance. *i-Perception*, *2*(1), 13–49. https://doi.org/10.1068/i0396

Wixted, J. T. (2020). The forgotten history of signal detection theory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *46*(2), 201–233. https://doi.org/10.1037/xlm0000732

Woods, D. L., Alain, C., Diaz, R., Rhodes, D., & Ogawa, K. H. (2001). Location and frequency cues in auditory selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(1), 65–74. https://doi.org/10.1037/0096-1523.27.1.65

Wu, W. (2017). Shaking up the mind's ground floor: The cognitive penetration of visual attention. *Journal of Philosophy*, *114*(1), 5–32. https://doi.org/10.5840/jphil201711411

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, 459–482. https://doi.org/10.1002/cne.920180503

Yeshurun, Y., Carrasco, M., & Maloney, L. T. (2008). Bias and sensitivity in two-interval forced choice procedures: Tests of the difference model. *Vision Research*, *48*(17), 1837–1851. https://doi.org/10.1016/j.visres.2008.05.008

Yik, M. S. M., Russell, J. A., & Barrett, L. F. (1999). Structure of self-reported current affect: Integration and beyond. *Journal of Personality and Social Psychology*, *77*(3), 600–619. https://doi.org/10.1037/0022-3514.77.3.600

Yip, M. (2002). *Tone*. Cambridge, UK: Cambridge University Press.

Zajonc, R. B. (1968). Attitudinal effects of mere exposure. *Journal of Personality and Social Psychology Monographs*, *9 (2, Pt. 2)*, 1–27. https://doi.org/10.1037/h0025848

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist*, *35*(2), 151–175. https://doi.org/10.1037/0003-066X.35.2.151

Zeimbekis, J., & Raftopoulos, A. (2015). The cognitive penetrability of perception: An overview. In J. Zeimbekis & A. Raftopoulos (Eds.), *The cognitive penetrability of perception: New philosophical perspectives* (pp. 1–56). New York, NY: Oxford University Press.

Zwicker, E., & Fastl, H. (1999). *Psychoacoustics: Facts and models* (2nd ed.). Berlin Heidelberg, Germany: Springer-Verlag.

Samenvatting

Een zelfde geluid kan voor verschillende personen of op verschillende momenten tot heel verschillende ervaringen leiden. Denk er bijvoorbeeld aan hoe de stampende beats van een wereldberoemde dance DJ klinken door de oren van een festivalganger en hoe dit zelfde geluid zal klinken door de oren van een omwonende van het festival. Terwijl de festivalganger haast in extase wordt meegevoerd door de opzwepende muziek, ervaart de omwonende misschien juist ernstige hinder. De hinder wordt wellicht nog eens versterkt door een slecht humeur of gevoeligheid voor harde prikkels.

Verschillende onderzoeken hebben inderdaad laten zien dat geluidshinder niet alleen wordt bepaald door de akoestische eigenschappen van het geluid (bijv. geluidsniveau en frequentiecomponenten) waaraan men wordt blootgesteld, maar dat ook niet-akoestische factoren, waaronder affectieve factoren, een rol spelen. Affectief wil hier zeggen dat er sprake is van een bepaalde mate van positieve of negatieve evaluatie of gevoel. Zowel de affectieve kwaliteit van het geluid (bijv. hoe onprettig het gevonden wordt), de affectieve toestand van de luisteraar (bijv. stemming), als de affectieve dispositie van de luisteraar (bijv. bepaalde persoonlijkheidstrekken) blijken van invloed op ervaren geluidshinder.

Dat geluidshinder onderhevig is aan affectieve invloeden is voor de meeste mensen goed voor te stellen. Geluidshinder zelf is immers grotendeels een affectieve reactie op geluid. De centrale vraagstelling van dit proefschrift gaat nog een stap verder en gaat dieper in op de auditieve ervaring en verwerking van geluid en de rol die affect hierin speelt. De vraag die we proberen te beantwoorden is in hoeverre basale perceptie, zoals toonhoogteperceptie en de gevoeligheid van het gehoor onderhevig zijn aan affectieve invloeden.

Het wordt vaak aangenomen dat perceptie een directe en waarheidsgetrouwe afspiegeling geeft van de wereld om ons heen. Echter, om verschillende redenen kan er aan deze aanname getwijfeld worden. Ten eerste is de informatie die onze zintuigen ons verschaft vaak incompleet of ambigu en moet deze met andere beschikbare informatie gecombineerd worden om een betekenisvolle waarneming te creëren. Ten tweede ondersteunt recent neurowetenschappelijk onderzoek naar de anatomie en werking van de hersenen het idee dat op alle niveaus van verwerking in het brein, inclusief perceptuele verwerking, verschillende informatie bronnen worden geïntegreerd.

Affect is volgens sommige onderzoekers een belangrijke bron van informatie. Onze affectieve toestand beïnvloedt mogelijk hoe ons brein binnenkomende sensorische informatie verwerkt en draagt bij aan de manier waarop we deze informatie ervaren. Dit zou kunnen verklaren waarom hoogtes hoger lijken wanneer we angstig zijn en waarom we ons sneller bewust worden van een omgevingsprikkel in onze ooghoek wanneer dit een angstopwekkende prikkel is, zoals een spin, dan wanneer dit een neutrale prikkel is, zoals een paddenstoel. De vraag in hoeverre affect de auditieve perceptie van de werkelijkheid kan beïnvloeden sluit hier dus goed bij aan.

De vraag of perceptie direct wordt beïnvloed door affect of cognitie is niet nieuw. Er bestaat al zeker meer dan een eeuw een grote discussie over in de psychologie en filosofie. Naar deze discussie wordt ook wel gerefereerd als het debat over "cognitieve en affectieve doordringbaarheid van perceptie". Om antwoord te geven op dit debat zijn er talloze onderzoeken gedaan, met name in het visuele domein, die laten zien dat de perceptuele beoordeling van omgevingsprikkels onderhevig is aan invloeden van affect of cognitie. Toch heeft dit tegenstanders van het idee dat perceptie doordringbaar is niet overtuigd. Een belangrijk argument dat tegenstanders aandragen is dat er vaak alternatieve verklaringen te geven zijn voor effecten van affect op metingen van perceptie. De respons van een proefpersoon op een perceptuele taak reflecteert vaak niet alleen de perceptie zelf, maar ook de (interne) beoordeling van deze perceptie aan de hand van een beslissingscriterium en de vertaling van deze beoordeling naar de respons. Om affectieve invloeden op perceptie zelf te onderzoeken is het dus belangrijk er zeker van te zijn dat een verandering van perceptuele beoordeling door een verandering in perceptie komt en niet door een verandering in het beslissingscriterium of de respons. Volgens de tegenstanders in het debat kan dit bij veel onderzoeken onvoldoende gegarandeerd worden. In de onderstaande discussie van de hoofdstukken komen we erop terug in hoeverre wij hierin geslaagd zijn.

Een complicerende factor in het debat over de doordringbaarheid van perceptie is dat de vraagstelling in het debat door verschillende wetenschappers en filosofen verschillend wordt begrepen. Dit komt bijvoorbeeld doordat ze verschillende opvattingen van perceptie hebben. Voor sommigen draait de kwestie om perceptie in de zin van subjectieve perceptuele ervaring, dus wat we zien, horen, ruiken, proeven of voelen. Anderen interpreteren perceptie als het verwerkingsproces van binnenkomende prikkels. De vraag gaat er dan om of er delen van dit proces zijn die volledige onafhankelijk opereren van affect of cognitie. Je kunt hierbij denken aan processen die er voor zorgen dat we de kenmerken van een omgevingsprikkel, zoals positie, oriëntatie of kleur in het visuele domein, of toonhoogte en luidheid in het auditieve domein kunnen abstraheren. Deze geabstraheerde kenmerken kunnen vervolgens gebruikt worden om de omgevingsprikkel te identificeren en te categoriseren. Nuances daargelaten, gaat hoofdstuk 2 meer over subjectieve waarneming, terwijl we in hoofdstuk 3 en 4 proberen een meer objectieve maat van een deel van het auditieve verwerkingsproces meten.

In Hoofdstuk 2 van dit proefschrift onderzochten we of de beoordeling van toonhoogteveranderingen onderhevig is aan invloeden van stemming. Het is een bekend fenomeen dat onze stemming onze oordelen kleurt. In een positieve stemming hebben we de neiging om de wereld om ons heen positiever te beoordelen dan wanneer we in een negatieve stemming zijn. In dit hoofdstuk onderzochten we in hoeverre dit soort stemmingscongruentie ook optreedt bij perceptuele beoordelingen, om precies te zijn de perceptie van de richting van ambigue toonhoogteveranderingen. We vonden een klein maar significant effect van stemming op de beoordeling van de richting van toonhoogteverandering. De toonhoogteverandering werd vaker beoordeeld als omhooggaand door luisteraars in een positieve (blije) dan in een negatieve (verdrietige) stemming.

Omdat we in dit onderzoek geïnteresseerd waren in subjectieve oordelen konden we niet vaststellen of de stemming de perceptie zelf beïnvloedde of het beslissingscriterium om de oordelen te maken. In hoofdstuk 3 en 4 keken we daarom naar de gevoeligheid van het gehoor met een taak die de bijdrage van het beslissingscriterium op de uitkomst van de taak zo veel mogelijk inperkte.

In Hoofdstuk 3 onderzochten we het effect van stemming op de gevoeligheid van het gehoor door de gehoordrempel in achtergrond ruis te meten. Dit wordt ook wel de gemaskeerde auditieve drempel genoemd. We vergeleken deze drempelwaarde tussen luisteraars in verschillende stemmingen. Dit keer keken we niet alleen naar blije en verdrietige stemmingen, maar ook naar angstige en kalme stemmingen. Hierdoor konden we de stemmingen niet alleen onderscheiden naar valentie, ofwel hoe positief of negatief de stemming is, maar ook naar activatieniveau, ofwel de mate van (fysiologische) opwinding die met de stemming gepaard gaat. We vonden geen effecten van valentie op de gevoeligheid voor tonen in ruis. Het effect van het activatieniveau van de stemming was niet eenduidig en leek af te hangen van de manier waarop de stemming was geïnduceerd. Dat wil zeggen, of muziek of plaatjes gebruikt waren om de stemming op te wekken. Verder onderzoek is nodig om uit te zoeken waarom dit zo is.

In Hoofdstuk 4 keken we nogmaals naar de relatie tussen auditieve sensitiviteit en affect. De focus lag hier niet op affect als toestand, zoals stemming, maar op affect als dispositie, ofwel affectieve neiging of karaktertrek. In het bijzonder onderzochten we de relatie tussen sensitiviteit en reactiviteit. Senstiviteit wordt hier begrepen als de gevoeligheid voor zwakke en subtiele prikkels, zoals net hoorbaar geluid. Met reactiviteit bedoelen we hier de mate van affectieve reactie die wordt ervaren bij blootstelling aan intense prikkels, zoals hard geluid. We gebruikten vragenlijsten om de neiging tot positieve en negatieve affectieve reactiviteit op intense prikkels en sensitiviteit voor zwakke prikkels te meten. Sensitiviteit voor zwakke prikkels werd daarnaast ook objectief gemeten als de gemaskeerde auditieve drempel, zoals in Hoofdstuk 3. De objectief gemeten sensitiviteit voor tonen in ruis, evenals zelf-gerapporteerde algemene sensitiviteit voor zwakke prikkels, bleek samen te hangen de affectieve reactiviteit op intense prikkels. Een belangrijke bevinding was dat deze samenhang pas duidelijk werd wanneer niet alleen reactiviteit geuit als negatief affect, maar ook reactiviteit geuit als positief affect werd meegenomen in de analyses. In eerdere studies naar de relatie tussen sensitiviteit en reactiviteit werd reactiviteit geuit als positief affect niet meegenomen. Ons onderzoek liet ziet dat het beeld van de verbanden tussen sensitiviteit en reactiviteit daardoor eerder dus incompleet was.

Uit de hierboven beschreven onderzoeken blijkt dat zowel affectieve toestand als affectdispositie tot op zekere hoogte een rol lijken te spelen bij de auditieve perceptie van affectief neutrale auditieve prikkels. We bespraken eerder dat naast affectieve toestand en dispositie ook de affectieve kwaliteit van een geluid de hinder door dit geluid kan beïnvloeden. Het is dus ook de moeite waard om de invloed van de affectieve kwaliteit van de auditieve prikkel zelf op de auditieve verwerking ervan beter te onderzoeken. Om dit te kunnen onderzoeken moeten we er voor zorgen dat we verschillen in perceptie door akoestische eigenschappen van het geluid (zoals verschillen in het geluidsniveau of de frequentie componenten van het geluid) kunnen uitsluiten. In Hoofdstuk 5 onderzochten we of evaluatief conditioneren hierbij zou kunnen helpen.

Evaluatief conditioneren is een vorm van conditioneren specifiek gericht op het veranderen van de valentie van een prikkel. Dit wordt gedaan door de prikkel herhaaldelijk te koppelen aan een positieve of negatieve prikkel. We vonden dat affectief neutrale geluiden die herhaaldelijk gepresenteerd werden gevolgd door een negatief of positief woord, respectievelijk meer negatief en, in mindere mate, positief geëvalueerd werden. Ook vonden we dat, wanneer na de conditioneringsprocedure het geluid herhaaldelijk werd gehoord zonder dat het door een affectief woord gevolgd werd, de geconditioneerde affectieve kwaliteit, hoewel iets afgezwakt, bleef bestaan. Evaluatief conditioneren zorgde dus voor een langdurige verandering van de affectieve kwaliteit van de geluiden. Dit is waardevol voor onderzoek naar de invloed van affectieve kwaliteit van geluid op de auditieve perceptie omdat hiermee de perceptie van hetzelfde geluid met verschillende affectieve betekenis bestudeerd kan worden. Op deze manier kan invloed van akoestische verschillen op de perceptie uitgesloten worden. Zo zou bijvoorbeeld onderzocht kunnen of we gevoeliger zijn voor affectieve geluiden dan neutrale geluiden door, zoals in hoofdstuk 3 en 4, de gehoordrempel in achtergrond ruis te meten voor evaluatief geconditioneerde negatieve, positieve en neutrale geluiden.

De bevindingen van de studies in dit proefschrift laten zien dat de beoordeling van toonhoogteveranderingen en de gehoordrempel in ruis samenhangen met de affectieve toestand of dispositie van de luisteraar. Verder onderzoek moet laten zien welke onderliggende auditieve processen precies worden beïnvloed door affect. Onze bevindingen onderstrepen het idee dat eenzelfde geluid voor verschillende personen of op verschillende momenten tot verschillende ervaringen kan leiden. Niet alleen de mate van hinder die we ondervinden van geluiden, maar ook meer basale auditieve perceptie lijkt samen te hangen met onze affectieve toestand of disposities. De verwevenheid van affect met onze perceptie kan in ons dagelijks leven ook weer verdere consequenties hebben omdat het deels bepaalt hoe we de wereld waarnemen.

Concluderend kunnen we stellen dat de studies in dit proefschrift suggereren dat aspecten van auditieve perceptie vatbaar zijn voor affectieve invloed. Dit past bij het idee dat ons brein informatie van perceptuele en niet-perceptuele bronnen integreert. Op deze manier kunnen we percepten vormen uit de vaak ruizige, incomplete, of ambigue auditieve input die we op een bepaald moment via onze oren binnen krijgen. Onze bevindingen geven een basis en stimulans om verder te onderzoeken via welke mechanismen deze integratie optreedt en waar in het brein dit gebeurt.

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Tijdens het afronden van mijn proefschrift dacht ik regelmatig aan de Zeeuwse wapenspreuk "luctor et emergo" ("ik worstel en kom boven"). In het Zeeuws wordt dit, vanwege de fonetische gelijkenis, ook begrepen als "lukt het vandaege nie, dan lukt het mèrrege" ("lukt het vandaag niet, dan lukt het morgen"). Wat betreft mijn proefschrift is die dag van morgen nu echt aangebroken. Het is gelukt, dankzij al jullie hulp, steun en liefde!

Curriculum Vitae

Anne Bolders was born in Tholen, The Netherlands, on July 10th 1981. After finishing high school (VWO) at Revius Lyceum in Doorn in 1999, she enjoyed a gap-year working and traveling in Tanzania and Australia. In 2000 she moved to Maastricht to study Psychology at Maastricht University. She completed two master tracks in Biological Psychology (Cognitive Neuroscience and Neuropsychology) and further expanded her education by following courses at the faculty of Arts and Culture and electives in Social Psychology. She graduated in 2006, after completing her master's thesis "Smoke Signals in the Brain: an fMRI Study into Brain Activity to Smoking Related Cues in Smokers", supervised by Dr. Anke Hammer, Prof. Dr. Bernadette Jansma and Prof. Dr. Rob Ruiter. From 2001 until 2007, during and after her studies, she worked as a research assistant for Prof. Dr. Rob Ruiter and Dr. Marieke Werry at the Applied Social Psychology Group, carrying out various research projects in applied social cognition and social cognitive neuroscience with a focus on public health promotion. From 2002 until 2007, during and after her studies, she also worked as a tutor, guiding Problem Based Learning (PBL) groups at the faculty of Psychology en Neuroscience, and later also at the University College of Maastricht University.

In 2008 she moved to Leiden to start her PhD project into affective influences on auditory perception. This project was carried out at the Cognitive Psychology Unit at the Faculty of Social Sciences of Leiden University, under supervision of Dr. Guido Band, Prof. Dr. Pieter Jan Stallen, and Prof. Dr. Bernhard Hommel. In 2013 she moved to Riyadh, Saudi Arabia, where she held a lecturer position and was involved in implementing a new Clinical Psychology Bachelor curriculum at the Princess Nourah University for women, in collaboration with Erasmus University Rotterdam. In 2015 she returned to the Netherlands and from 2016 until 2018 she worked as tutor and trainer at the School of Social and Behavioral sciences of Erasmus University Rotterdam. Over the years she kept working towards completing her PhD project and finished her dissertation titled "Hearing while Feeling — Affective Influences on Auditory Perception" in 2020.

Currently, she is working for the COVID-19 contact tracing team of the GGD Rotterdam-Rijnmond (public health service) in Rotterdam.