Sound, mind and emotion

Publications from
The Sound Environment Centre
at Lund University

Report no. 8

Sound, mind and emotion

Research and aspects

Texts from a series of interdisciplinary symposiums arranged
2008 by The Sound Environment Centre at Lund university, Sweden.
Lund 2009

ISSN 1653-9354
ISBN 978-91-976560-1-6

Editor: Frans Mossberg
Printed at MEDIA-TRYCK, Lund 2009

Contents

Sound, Mind and Emotion

- Editor´s foreword

In the spring of 2008 a series of interdisciplinary symposiums were arranged in Lund by the Sound Environment Centre at Lund university. The main objective was to further understanding of how sound and sound environments can affect humans on personal, emotional and psychological levels. The three different symposiums had different perspectives. The first one focused on how sound can affect us with intensified strength in times of emotional crisis, trauma or catastrophic events. The second topic was to investigate how sound is perceived by subjects in mental disturbances of various kinds, and the third finally discussed oversensitivity to sound – hyperacusis – as well as hearing impairments such as tinnitus or similar.

Patrik Juslin opens this volume by presenting an attempt to find out how the human brain arouses emotions from sounds, by suggesting a analytical model originally applied to music. This model consists of a number of psychological mechanisms, organized by their approximate place in the line of human evolution. Predictions are then being made on how various parameters affects these mechanisms, as well as different brain regions. Juslin argues that this theoretical framework provides a more precise tool for understanding interaction of sound, music and emotion, something that can also be useful in therapeutic situations.

Professor Ulf Rosenhall gives a thorough description of the details of the complexity of the whole auditory system from ear to brain, and the various impairments that can affect hearing on different levels. Drawing on psychoacoustics and neurophysiology Professor Sören Nielzén et al. follows with an overview of the clinical and scientific background in theory and practise, of the so called “S-detect method”, developed as an aid to diagnostics and the treatment of schizofrenia in psychiatry. This method uses responses to certain sound stimuli to discriminate between heatlhy subjects and persons with schizofrenia, claiming to do so with a certainty of 90 %.

That noise can affect people in unexpected ways is discussed hery by Sverker Sikström and Göran Söderlund. By, amongst other things, looking at brain arousal and dopamine production, their studies shows that cognitive performance of ADHD children sometimes can benefit from noise at appropriate levels.

Specializing on the treatment of tinnitus and hyperacusis prof. Gerhard Andersson draws a brief description of diagnosis, treatment and research on impairments such as these.

From the sound world of preschools Kerstin Persson Waye, at the Department of Occupational and Environmental Medicine at Sahlgrenska University Hostpital in Gothenburg, reports on the sound environment at day care centers from the child´s perspective. The study shows, through in-place measurements and interviews, that children tend to evaluate sounds by the consequenses they have for them in their immediate perception as well in their own bodies, and adopt avoidance strategies to loud or unwanted sounds.

Preschools and day care sound enviroments are not only hard on children´s hearing, but also on the hearing of the staff, and well known to produce tiredness, sick leave absence and hearing impairments. Staff who have developed impaired hearing from their work and continue to work face double trouble as far as hearing goes. Björn Lyxell et. al show that children´s cognitive skills will be negatively affected as they have to work harder to keep up with decoding their sound enviroment than their normal hearing collegues, thus resulting in problems of fatigue and social alienation, as those with impaired hearing always have to listen actively not to miss out, and in reality seldom have the possibility of a relaxed passive listening.

Åke Iwar who is a practicing psychologist specialising in trauma treatment and also a member of the SOS International Crisis Group in Copenhagen, gives a picture of the role that experiences and memories of sound impressions can play in therapeutic treament of victims of serious accident and cathastrophies, like that of the tsumani in Thailand recently.

Finally Kerstin Bergh-Johannesson, at the National Center for Disaster Psychiatry, discusses an unorthodox method of treatment of traumatic memories in patiens with postraumatic stress symptoms, memories that are repeatedly triggered by internal or external stimuli like sounds, thoughts or pictures.

This is the eighth in a series of reports from The Sound Environment Centre at Lund university.

The centre wishes to thank all authors for their participation.

2009-08-28 Frans Mossberg

Sound of music:

Seven Ways in which the Brain Can Evoke Emotions from Sounds

Patrik N. Juslin

Sound moves us. It may cause great pleasure as well as great pain. Nowhere is this more apparent than in the world of music – often referred to as "that one of the fine arts which is concerned with the combination of sounds with a view to beauty of form and the expression of emotion" (Oxford English Dictionary, 3rd ed.). Emotional reactions to music have fascinated people since Ancient Greece (Budd, 1985), though it is only recently that researchers have made progress in understanding how such reactions come about (Juslin & Västfjäll, 2008). It turns out that our reactions to music tell us a story about who we are – both as *individuals* (e.g., in terms of our memories, preferences, and personalities) and as a *species* (e.g., in terms of our innate human disposition to use sounds as sources of information in our inferences about future events, potential danger and affective states of other individuals).

Although music arouses positive emotions more frequently than negative emotions (Juslin et al., 2008), music does arouse *some* negative emotions such as sadness and irritation quite frequently. If we consider sounds more generally, it is even more common that sounds are a cause of negative emotions and stress (Västfjäll, in press). As shown in some of the other contributions to this volume, specific sounds may also be connected to traumatic life events in *post-traumatic stress disorder* (PTSD) such that hearing a certain sound may continue to arouse negative emotions long after the event in which the sound originally occurred. Strange as it may seem, the underlying mechanisms that cause these responses may be partly similar to those that arouse positive emotions in music listening. Hence, systematic knowledge about the mechanisms that underlie emotional reactions to music could be of potential importance also for therapeutic attempts to address aversive reactions to sounds in PTSD.

In this chapter, I will propose a psychological framework for understanding how the brain evokes emotional reactions from sound waves. The framework was developed with music especially in mind, although as will be apparent, it is one of the assumptions of the framework that most of the psychological mechanisms apply to perception of sound more generally. In the following, I first discuss the role of psychological theory in studying how the human brain arouses emotions from sounds. Then, I outline a theoretical framework, featuring six mechanisms and a set of predictions that can guide future research. Finally, I consider the implications of this framework for both empirical research and applications in therapy.

Why is psychological theory important?

The important role of psychological theory in studies of music and emotion may be illustrated with regard to a recent series of *neuropsychological* studies (for a review, see Koelsch, 2005). First of all, it should be noted that emotional responses can be analyzed along a number of different dimensions from a neuropsychological perspective. Thus, for instance, one may distinguish brain regions in terms of whether they involve *perception* or *experience* of emotions (Blonder, 1999; Davidson, 1995; Tucker & Frederick, 1989). For example, perceiving a facial expression as "happy" is different from feeling "happy". One may also distinguish brain regions in terms of *discrete emotional states* (Damasio, Grabowski, Bechara, Damasio, Ponto, Parvizi, & Hichwa, 2000; Murphy, Nimmo-Smith, & Lawrence, 2003; Panksepp, 1998; Phan, Wager, Taylor, & Liberzon, 2002). That is, the experience of "fear" might activate a different brain region than the experience of "joy". Yet another approach, which ultimately may be more fruitful in this context, is to analyze brain regions in terms of distinct *psychological processes* or *functions* (Cabeza & Nyberg, 2000). For instance, an emotion aroused by an episodic memory may involve a different set of brain regions than an emotion aroused by a startle response.

In this chapter, I shall argue that an analysis of underlying psychological processes is crucial for an understanding of emotional reactions to sounds. Indeed, the coupling of psychological predictions with functional brain imaging techniques is probably one of the most promising avenues in the study of music and emotion. While imaging studies could inform and constrain psychological theorizing, psychological theories could organize data from imaging studies. Unfortunately, this is *not* how current neuropsychological research on emotional reactions to music has been conducted (Juslin & Västfjäll, 2008).

A review of the literature reveals that a number of different brain regions have been implicated in studies of emotional reactions to music, including the thalamus, cerebellum, hippocampus, amygdala, prefrontal cortex, orbitofrontal cortex, midbrain, insula, Broca's area, nucleus accumbens, visual cortex, and supplementary motor areas. Note, however, that different regions have been activated in different studies, without any explanation of these differences (e.g., Bauer Alfredson et al., 2004; Blood & Zatorre, 2001; Blood et al., 1999; Brown et al., 2004; Gosselin et al., 2006; Koelsch et al., 2006; Menon & Levitin, 2005).

How can we bring some order to the inconsistent findings from previous research? The solution is to consider the underlying psychological mechanisms that give rise to the emotional responses. Brain imaging studies have tended to simply present listeners with supposedly "emotional" music to explore which areas may be activated by this stimulus. In some cases listeners have been asked to bring their own music to increase the chance that the music will be "effective". Rarely, however, have researchers manipulated - or at least controlled for - the underlying mechanism that induced the emotion. As I will show, music can induce emotions in many different ways, and what brain regions are activated will depend on the precise mechanism involved. Hence, if researchers can manipulate (or at least control for) induction mechanisms in future experiments, they may be better able to account for obtained activation patterns. In the following, I briefly outline a framework that aims for a more theory-driven approach to studying musical emotions.

A novel theoretical framework

Although most scholars regard the question of *how* music evokes emotions as the primary issue (e.g., Dowling & Harwood, 1986, p. 202), a literature search reveals that few studies make any attempt to test a theory about the psychological mechanism that underlies emotional reactions to music. Yet, such reactions are intriguing. This is because in the paradigmatic case, an emotion is evoked when an event is appraised as having the capacity to influence the goals of the perceiver somehow. Music does not appear to have any capacity to further or block goals in life. Thus, researchers have been forced to come up with alternative mechanisms that make more sense in a musical context.[1]

I shall use the term "psychological mechanism" broadly in this chapter to refer to any information processing that leads to the induction of emotions through listening to music. The processing may be simple or complex. It may be available to consciousness or not. The crucial thing is that the mechanism somehow takes the music as its "object". Most scholars who have written about possible mechanisms have limited themselves to only one or a few mechanisms (e.g., Levinson, 1997), or have argued that the "default" mechanism for induction of emotions – *cognitive appraisal* – is most suitable to explain emotional reactions to music (e.g., Waterman, 1996).

In contrast, Juslin and Västfjäll (in press) outlined a novel framework, featuring six psychological mechanisms (besides cognitive appraisal) through which music may evoke emotions. The mechanisms are: *brain stem reflexes*, *evaluative conditioning*, *emotional contagion*, *visual imagery*, *episodic memory*, and *musical expectancy* (explained further below). Juslin and Västfjäll argue that one may think of these mechanisms as consisting of a number of distinct "brain functions" that have developed gradually and in a specific order during the evolutionary process – from simple sensations to syntactical processing (e.g., Gärdenfors, 2003). The mechanisms are seen as information-processing devices at different levels of the brain that utilize different means to track significant aspects of the environment, and that may lead to conflicting outputs in some contexts. All mechanisms have their origin outside the musical domain. Because the mechanisms depend on brain functions with different evolutionary origins, each mechanism is expected to have unique

1 However, musical induction of emotions through a cognitive appraisal may occur sometimes, such as when our 'goal' to go to sleep at night is 'blocked' by a neighbor playing loud music.

characteristics that one should be able to demonstrate, for instance, in experiments.

Below, I first briefly define each mechanism and then outline theoretical predictions for each mechanism – in particular, as they pertain to neural correlates. I hope that this may contribute to more hypothesis-driven approaches to brain imaging studies of music and emotion (for further discussion and evidence, see Juslin & Västfjäll, 2008).

Psychological mechanisms

Building on the work of the pioneers in this field (Berlyne, 1971, Meyer, 1956) as well as on more recent research (Juslin & Sloboda, 2001), Juslin & Västfjäll (2008) suggested the following six mechanisms:

Brain stem reflex refers to a process whereby an emotion is induced by music because one or more fundamental acoustical characteristics of the music are taken by the brain stem to signal a (potentially) important and urgent event. All other things being equal, sounds that are sudden, loud, dissonant, or feature fast patterns induce arousal in the listener. The responses reflect the immediate impact of simple auditory sensations.

Evaluative conditioning (EC) refers to a process whereby an emotion is induced by music simply because this stimulus has been paired with other positive or negative stimuli. For instance, a specific piece of music may have occurred repeatedly together in time with a specific event that always makes you happy such as meeting your best friend. Over time, through repeated pairings, the music itself will, eventually, arouse happiness even in the absence of the friendly interaction.

Emotional contagion refers to a process whereby an emotion is induced by music because the listener perceives the emotion expressed in the music, and then 'mimics' this expression internally, which by means of either peripheral feedback from muscles, or a more direct activation of the relevant emotion representations in the brain, leads to an induction of the same emotion.

Visual imagery refers to a process whereby an emotion is induced in a listener because he or she conjures up visual images (e.g., of a beautiful landscape) while listening to the music. The emotions experienced are the result of a close interaction between the music and the images. Listeners appear to conceptualize the structure of the music in terms of a metaphorical, nonverbal mapping between the music and image-schemata grounded in bodily experiences; for instance, hearing the melody as "moving upward". Listeners react to the mental images much in the same way as they would to the corresponding visual stimuli in the "real" world (e.g., reacting positively to a beautiful nature scene).

Episodic memory refers to a process whereby an emotion is induced in a listener because the music evokes a memory of a particular event in the listener's life (often referred to as the "Darling they are playing our tune" phenomenon). When the memory is evoked, so is also the emotion associated with the memory, and this emotion may be relatively intense – perhaps because the psychophysiological reaction pattern to the original event is stored in memory along with the experiential contents.

Music expectancy refers to a process whereby an emotion is evoked in a listener because a feature of the musical structure violates, delays, or confirms the listener's expectations about the continuation of the music. Thus, for example, the sequential progression of E-F# sets up the expectation that the music will continue with G#. If this does not happen, a listener familiar with the musical idiom could become, say, surprised. The expectations are based on the listener's previous experiences of the same style of music.

Theoretical hypotheses

By synthesizing theories and findings from several research domains outside music, Juslin and Västfjäll (2008) were able to offer the first set of hypotheses that may help music researchers to distinguish among different mechanisms in future research. Table 1 shows the preliminary hypotheses. The mechanisms are listed in the approximate order in which they can be assumed to have appeared during evolution (see Gärdenfors, 2003; Joseph, 2000; Tulving, 1983).

The 66 predictions can be divided into two subgroups: the first subgroup concerns characteristics of the psychological mechanism as such. *Survival value of brain function* describes the most important benefit that each brain function brought to organisms that possessed this function. *Information focus* specifies broadly the type of information that each mechanism is processing. *Ontogenetic development* concerns the approximate time in human development when respective mechanism begins to have a noticeable effect on emotional responses to music. *Key brain regions* describes those regions of the brain that have been most consistently associated with each mechanism in functional brain imaging studies (detailed below). *Cultural impact and learning* refers to the extent to which each mechanism is influenced differently by music that varies from one culture to another.

A second group of characteristics (see Table 1) concerns the specific nature of the emotion induction process of the respective mechanism. Hence, *Induced affect* specifies which emotional states might be expected to be induced, depending on the mechanism. *Induction speed* refers to how much time each mechanism requires, in relation to other mechanisms, for an emotion to occur in a specific situation. *Degree of volitional influence* refers to the extent to which a listener him- or herself can actively influence the induction process (e.g., through focus of attention, active recall, etc.). *Availability to consciousness* is the extent to which at least *some* aspects of the induction process are available to the listener's consciousness, so that the listener may be able to explain his or her response. *Modularity* refers to the extent to which the mechanism may function as an independent and information-encapsulated "brain module" that can be activated in parallel with other psychological processes. *Dependence on musical structure* refers to the relative extent to which the induction depends on the precise structure or style of the music the listener is hearing.

Table 1: Hypotheses for six psychological mechanisms through which music might induce emotions (adapted from Juslin & Västfjäll, 2008).

Nature of mechanism	*Characteristic*		
Mechanism	Survival value of brain function	Information focus	Ontogenetic development
Brain stem reflex	Focusing attention on potentially important changes or events in the close environment	Extreme or rapidly changing basic acoustic characteristics	Prior to birth
Evaluative conditioning	Being able to associate objects or events with positive and negative outcomes	Covariation between events	Prior to birth
Emotional contagion	Enhancing group cohesion and social interaction, e.g. between mother and infant	Emotional motor expression	First year
Visual imagery	Permitting internal simulations of events that substitute for overt and risky actions	Self-conjured visual images	Pre-school years
Episodic memory	Allowing conscious recollections of previous events and binding the self to reality	Personal events in particular places and at particular times	3-4 years
Musical expectancy	Facilitating symbolic language with a complex semantics	Syntactic information	5-11 years

Table 1 (continued)

Nature of mechanism	*Characteristic*	
Mechanism	Key brain regions	Cultural impact/learning
Brain stem reflex	Reticular formation in the brain stem, the intralaminar nuclei of the thalamus, the inferior colliculus	Low
Evaluative conditioning	The lateral nucleus of the amygdala, the interpositus nucleus of the cerebellum	High
Emotional contagion	'Mirror neurons' in the pre-motor regions, right inferior frontal regions, the basal ganglia	Low
Visual imagery	Spatially mapped regions of the occipital cortex, the visual association cortex, and (for image generation) left temporo-occipital regions	High
Episodic memory	The medial temporal lobe, especially the hippocampus, and the right anterior prefrontal cortex (applies to memory retrieval)	High
Musical expectancy	The left perisylvian cortex, 'Broca's area', the dorsal region of the anterior cingulate cortex	High

Table 1 (continued)

Nature of induction process	*Characteristic*		
Mechanism	Induced affect	Induction speed	Degree of volitional influence
Brain stem reflex	General arousal, unpleasantness vs. Pleasantness	High	Low
Evaluative conditioning	Basic emotions	High	Low
Emotional contagion	Basic emotions	High	Low
Visual imagery	All possible emotions	Low	High
Episodic memory	All possible emotions, although especially nostalgia	Low	Medium
Musical expectancy	Surprise, awe, pleasure, ‘thrills’ disappointment, hope, anxiety	Low	Low

Table 1 (continued)

Nature of induction process		*Characteristic*	
Mechanism	Availability to consciousness	Modularity	Dependence on musical structure
Brain stem reflex	Low	High	Medium
Evaluative conditioning	Low	High	Low
Emotional contagion	Low	High	Medium
Visual imagery	High	Low	Medium
Episodic memory	High	Low	Low
Musical expectancy	Medium	Medium	High

From: Juslin & Västfjäll (2008), adapted by permission from the Cambridge University Press.

For further theoretical and empirical support of the different hypotheses, see the original article.

Key brain regions: Overview

Returning to our previous discussion of functional brain imaging studies, it may be useful to consider the key brain regions associated with each mechanism. However, first of all, it should be noted that emotional responses to music may be expected to involve three general types of brain regions: (1) regions virtually always involved when music is perceived (e.g., the primary auditory cortex), (2) regions virtually always involved in the conscious experience of emotion – regardless of the "source" of the emotion (candidates include the rostral anterior cingulate and the medial prefrontal cortex; e.g., Lane, 2000, pp. 356-358), and (3) regions involved in emotional information-processing that *differ* depending on the precise mechanism causing the emotion. Hence, although responses to music are likely to involve several regions of the brain, the predictions in Table 1 concern only the last set of regions (i.e., those that can help researchers to *discriminate* between the underlying mechanisms). It should be noted that several of the processes that these mechanisms entail (e.g., syntactical processing, episodic memory) do not in themselves imply that emotions have been evoked – they may also occur in the absence of emotion. However, whenever emotional responses to music occur, one or more of the mechanisms will be involved, and, hence, at least one associated sub-process should be observable as well.

Brain stem reflexes

The precise neurophysiological processes that underlie brain stem reflexes are not fully understood, although evidence suggests that they occur in close connection with the reticular formation of the brain stem and the intralaminar nuclei of the thalamus, which receive inputs from the auditory system (see Kinomura et al., 2006). The brainstem is an ancient structure of the brain subserving several sensory and motor functions, including auditory perception and the mediation and control of attention, emotional arousal, heart rate, breathing, and movement (Joseph, 2000). The reticular formation is able to quickly induce arousal so that attention can be selectively directed at sensory stimuli of potential importance. The system exerts its widespread influences on sensory and motor functions and arousal through neurotransmitters such as norepinephrine and serotonin. While the system may be activated and inhibited by the amygdala, hypothalamus, and orbitofrontal cortex, it may also be activated *independently* of these structures in a more "reflex-like" manner (Tranel, 2000). Brain stem reflexes to music rely on the early stages of auditory processing. When an auditory signal reaches the primary auditory cortex, it has already undergone several analyses by such brain structures as the superior olivary complex, the inferior colliculus, and the thalamus. Accordingly, alarm signals to auditory events which suggest "danger" may be emitted as early as at the level of the inferior colliculus. Brain stem reflexes appear to be largely "hard-wired" in the brain.

Evaluative conditioning

EC is often regarded as a special kind of "classic" conditioning, with some unusual characteristics (e.g., De Houwer et al., 2001). First, EC can occur even if the participant is *unaware* of the contingency of the associated stimuli. In fact, studies have shown that EC responses can be both established and arouse emotions without awareness (Martin et al., 1984). Second, EC appears to be fairly resistant to extinction, as compared to classic conditioning (Diaz et al., 2005). Hence, once a piece of music has been associated with a certain emotional outcome, this association may be quite persistent. Although EC has not been studied much in regard to music, compared to other mechanisms, two studies have reported EC effects with music (Blair & Shimp, 1992; Razran, 1954).

EC depends on unconscious, unintentional, and effortless processes, which involve sub-cortical regions of the brain, such as the amygdala and the cerebellum (Fanselow & Poulus, 2005; Johnsrude et al., 2000; LeDoux, 2000; Sacchetti et al., 2005; Thompson, 2005). In the EC process, it is plausible that the amygdala is particularly involved in the evaluation of the emotional stimulus, whereas the cerebellum is involved in the timing of the response (Cabeza & Nyberg, 2000). In addition to these brain areas, one can expect some hippocampal activation if the conditioning depends strongly on the specific context. However, the amygdala appears to be required for EC, whereas the hippocampus is not (LeDoux, 2000).

Emotional contagion

People commonly catch the emotions of others when seeing their facial expressions or hearing their vocal expressions (e.g., Hatfield, Cacioppo, & Rapson, 1994; Neumann & Strack, 2000). Because music commonly features acoustic patterns similar to those that occur in emotional speech (see Juslin & Laukka, 2003), it has been argued that we might get aroused by voice-like features of music that lead us to "mimic" the perceived emotion internally. That emotional reactions to music could involve contagion effects is supported by findings that the perception of "happy" and "sad" music may induce the corresponding emotions in listeners, as indicated by experiential, physiological, and expressive emotion components (Lundqvist, Carlsson, Hilmersson, & Juslin, 2009).

Recent research has suggested that the process of emotional contagion may occur through the mediation of so-called "mirror neurons" discovered in studies of the monkey pre-motor cortex in the 1990's (di Pellegrino et al., 1992). It was found that the mirror neurons discharged both when the monkey carried out an action and when it observed another individual carrying out a similar action. Direct evidence for "mirror neurons" in humans is still lacking, but there is indirect evidence: Several studies have shown that when individuals observe an action carried out by another individual, the motor cortex may become active in the absence of overt motor activity (Rizzolatti & Craighero, 2004).

While the idea of emotional contagion remains speculative in relationship to music, a recent fMRI study by Koelsch et al. (2006) found that music listening activated brain areas related to a circuitry serving the formation of pre-motor representations for vocal sound production even though no singing was observed among the participants. Koelsch et al. concluded that this may reflect a mirror-function mechanism. The findings support the idea that listeners may mimic the emotional expression of the music internally. Thus, emotional contagion from music might be assumed to involve two types of brain regions. First, several studies have indicated that perception of emotion from the voice (and thus presumably of emotion from voice-like characteristics of music) may involve particularly the right inferior frontal regions and the basal ganglia (see Adolphs, 2002; Adolphs et al., 2002; Buchanan et al., 2000; Cancelliere & Kertesz, 1990; George et al., 1996). Also, we would expect to find activation of "mirror neurons" in pre-motor regions, in particular the areas involved in vocal sound production (Koelsch et al., 2006).

Visual imagery

Visual imagery is commonly defined as an experience which resembles perceptual experience, but that occurs in the absence of relevant sensory stimuli. The primary issue in imagery research has been whether visual imagery involves a distinctively "pictorial" representation of events in mind or a propositional representation? The pictorial view is supported by findings that many brain regions that are activated during visual perception are similarly activated when a person is involved in imagery (for reviews, see e.g., Farah, 2000; Ganis et al., 2004). Specifically, both studies with focally brain-damaged patients and brain imaging studies of normal participants have shown that visual representations in the occipital lobe known to be spatially mapped are activated in a "top-down" manner during imagery (Charlot et al., 1992; Goldenberg et al., 1991). ERP studies have further suggested that imagery involves the same visual cortical areas that are involved in early visual processing (Farah, 2000).

It has been proposed that music may be particularly effective in stimulating mental imagery (Osborne, 1980; Quittner & Glueckauf, 1983), and several studies also indicate that imagery can be effective in enhancing emotional reactions to music in listeners (e.g., Band, Quilter, & Miller, 2001-2002). However, what is characteristic of visual imagery as a mechanism is that the listener is able to influence the process to a considerable extent and therefore is very much a "co-creator" of the emotions evoked by the music. Although images may sometimes come into the mind unbidden, in general a listener may conjure-up, manipulate, and dismiss images at will. Hence, whereas the "bottom-up" process of visual perception is "automatic", visual imagery appears to require the intervention of an attention-demanding process of image generation. Though the localization of this image generation process is a controversial issue, a number of studies suggest a left temporo-occipital localization (Farah, 2000). Thus, activation of visual association cortex including occipital cortex during music listening may indicate that the listener is involved in music-stimulated visual imagery.

Episodic memory

Music often evokes memories (Gabrielsson, 2001; Juslin et al., 2009; Sloboda, 1992). When the memory is evoked, so is also the emotion associated with the memory (Baumgartner, 1992). Though evaluative conditioning is also a form of memory, episodic memory differs from conditioning in that it involves a conscious recollection of a previous event in time, preserving a lot of contextual information (Tulving, 1983). Also, the two kinds of memory have different process characteristics and brain substrates (Table 1).

Episodic memory can be divided into different stages (encoding, storage, retrieval). Note that different brain regions may be involved depending on the stage of the memory process. Here, I focus on the *retrieval* stage of the memory process, which may be most important in order to be able to differentiate the mechanisms in a listening experiment. Previous research has consistently indicated that the conscious experience of recollection of an episodic memory involves the medial temporal lobe, in particular hippocampus, and the right anterior prefrontal cortex (e.g., Nyberg et al., 1996; Schachter et al., 1996; see also Cabeza & Nyberg, 2000).

Musical expectancy

Musical expectancy does not simply refer to *any* unexpected event that might occur in regard to music. Musical expectancy refers to those expectancies that involve *syntactic* relationships among different parts of the music's structure (Patel, 2003; see also Meyer, 1956, 2001). Like language, music consists of perceptually discrete elements, organized into hierarchically structured sequences according to "well-formedness" rules. Thus, it is a common view among music theorists that most musical styles are, in principle at least, describable by a grammar (Lerdahl & Jackendoff, 1983). It is only through the perception of this syntax that the relevant musical expectations arise. These expectations are based on the listener's previous experience of the musical style (e.g., Carlsen, 1981). Emotional reactions are evoked when a listener's musical expectations are disrupted somehow – for instance by new or unprepared harmony (Steinbeis, Koelsch, & Sloboda, 2006).

Lesion studies suggest that several areas of the left perisylvian cortex is involved in different aspects of syntactic processing (Brown, Hagoort, & Kutas, 2000). Relatively few brain imaging studies of language so far have looked at processes at the sentence level and beyond. A few studies have indicated that especially parts of Broca's area increase their activity when sentences increase in syntactic complexity (e.g., Caplan et al., 1998; Stromswold et al., 1996). Similarly, a few studies using MEG or fMRI have revealed that syntactical processing of music is processed in Broca's area (see Maess, Koelsch, Gunter, & Friederici, 2001; Tillman, Janata, & Bharucha, 2003). It has been found that violations of musical expectancy activate the same brain areas as have previously been implicated in violations of syntax in language. Patel (2003) has thus argued that syntax in language and music share a common set of processes for syntactical integration (localized around Broca's area) that operate on different structural representations in more posterior brain regions.

In addition to the areas involved in syntactic processing, which might work in fairly automatic fashion (e.g., Koelsch et al., 2002), musical expectancy also probably involves a monitoring of musical expectancies and conflicts between expected and actual musical sequences. This monitoring might involve parts of the anterior cingulate cortex as well as the prefrontal cortex (Botvinick, Cohen, & Carter, 2004; Cabeza & Nyberg, 2000).

In sum, we see that different mechanisms are likely to involve partly different brain regions, which could explain the inconsistent findings in previous functional brain imaging studies, since these studies have not controlled for underlying mechanisms.

Implications of the novel framework

Implications for research

One implication of the novel framework is that it may resolve many disagreements in the field. Apparent contradictions of different approaches may be partly reconciled by observing that they focus on different mechanisms. Hence, the framework might help to resolve past disagreement regarding what emotions music can evoke, how early musical emotions develop, whether listeners are "active" or "passive" in inducing emotions, how much time it takes to induce an emotion through music, and whether musical emotions are innate or learned responses – it all depends on the mechanism concerned (Table 1).

The most crucial implication of the new framework for studies of music and emotion is that it will not be sufficient to induce and study musical emotions *in general*. In order for data to contribute in a cumulative fashion to our knowledge, researchers must try to specify, as far as possible, the mechanism involved in each study. Otherwise studies will yield results that are inconsistent or that cannot be given a clear interpretation. As noted earlier, neuropsychological studies offer one example of this problem. The studies have tended to simply present "emotional music" to listeners without manipulating or at least controlling for the underlying induction mechanism. This makes it exceedingly difficult to understand what the obtained neural correlates actually reflect in each study ("It is not possible to disentangle the different subcomponents of the activation due to limitations of this experimental design", Bauer Afredson et al., 2004, p. 165). Given the aim to explore emotional reactions to music, one would expect the manipulation of musical stimuli to be crucial to the task. Yet, stimuli used so far have been selected non-systematically (e.g., instrumental songs of the rembetika style, joyful dance tunes, listener-selected music). The fact that different studies have reported activations of different brain regions does suggest that different mechanisms were involved. But after the fact, there is no way of knowing. This shows that *musical emotions cannot be studied without regard to how they were evoked*. On the other hand, if researchers could *manipulate* induction mechanisms in future listening experiments, they would be better able to explain the obtained brain activation patterns. Indeed, to the extent that we can obtain systematic relations among mechanisms and brain regions, we might eventually be able to discriminate between the mechanisms based on brain indices alone. To facilitate studies of music and emotion, we should try to develop standard paradigms and tasks that reliably evoke specific emotions in listeners through each of the mechanisms mentioned earlier. (This would be somewhat analogous to the different tasks used to measure distinct memory systems; e.g., Tulving, 1983).

Implications for therapeutic applications

The novel framework could also have implications for therapy that involves sound, one way or the other. For example, the various mechanisms are related to a number of different methods in music therapy (e.g., Bunt & Hoskyns, 2002) which involve music in procedures to accomplish different aims. One of the six mechanisms in the framework is already used systematically in music therapy – namely, the visual imagery mechanism. Helen Bonny developed a method, *Guided Imagery and Music* (GIM), where a "traveler" is invited to "share" his or her images as they are experienced in real time during a pre-programmed sequence of music (Bonny & Savary, 1973). Such music-induced imagery may help to facilitate the expression, identification, and experience of specific emotions in patients. Imagery may also yield a state of deep relaxation, with health benefits such as reduced cortisol levels (McKinney, Antoni, Kumar, Tims, & McCabe, 1997). To help to activate the visual imagery mechanism, one may choose music with characteristics that seem especially effective in stimulating vivid imagery, such as repetition, predictability in melodic, harmonic, and rhythmic elements, and slow tempo (McKinney & Tims, 1995). In order to further increase the relaxing effects of the music – if that is the intended effect of the therapy – one can make sure to choose music with features *opposite* to those that activate the brain stem reflex mechanism (and increase the arousal level of the listener). That is, one should select music that features a slow tempo, low sound level, soft timbre, and, in particular, no sudden changes in the musical parameters.

There are other, less obvious ways in which mechanisms can be involved in specific kinds of music therapy. One of the oldest methods in music therapy is the so-called "iso principle" (Altshuler, 1954). This means that, in order to modify the mood of the patient, one must first match the patient's mood using music with the same emotional expression (e.g., "sad" music if the patient is feeling "sad"), and then begin to gradually change the expression of the music in the direction of the desired mood (e.g., gradually increase the tempo and pitch to aim for "joy"). In this process, the emotional contagion mechanism is of central importance. Music therapists may find it useful to take stock of current theory on this mechanism in order to maximize the effectiveness of the method. For instance, if musical expression is based on its similarities with emotional speech, as hypothesized in the new framework, then music therapists should create musical stimuli based on similar emotion-specific patterns of acoustic parameters in speech and music (Juslin & Laukka, 2003, Table 7), perhaps also using timbres that are particularly "voice-like", such as the cello and the violin. This might increase the chances that the therapist is able to "steer" the patient's mood in the desired direction.

Music can also be used in therapy to create new and positive associations to stimuli that evoke, say, anxiety in patients. Such procedures involve the evaluative conditioning mechanism, and theoretical knowledge about the characteristics of this mechanism (see Table 1) might help therapists to design more efficient procedures. For instance, to make the conditioning procedure as effective as possible, perhaps the conditioning should occur *outside* awareness – for instance, by giving the patient some task that requires his or her attention. (Research has indicated that evaluative conditioning is more easily established outside conscious awareness; see De Houwer et al., 2005; Razran, 1954.)

The above discussion focuses on how sounds of music can be beneficial in therapy. Sometimes, however, the sounds themselves are part of the problem. As I mentioned in the introduction, PTSD involves cases where specific sounds are perceived as extremely unpleasant because they are somehow associated with traumatic and stressful events in the patient's past. In such instances, the two mechanisms based on memory (evaluative conditioning, episodic memory) are most relevant. Memories associated with sounds may give rise to anything from nostalgic recognition to sheer fear. Studies of fear conditioning have provided examples of "one-trial-learning" to simple sounds (LeDoux, 2000). Further studies are needed to clarify the exact degree of generality and discriminability of sounds involved in EC. How similar to the sound occurring in the original traumatic event must a subsequent sound be in order to elicit the conditioned response?

Note that the two memory mechanisms (evaluative conditioning, episodic memory) have quite different implications for treatments, as suggested by the various hypotheses presented earlier. If a negative reaction to a sound is based on the largely sub-conscious evaluative conditioning mechanism, treatments that focus on conscious thought patterns may have little effect. Instead, the treatment of choice to get rid of the negative emotion associated with the sound may be to create new associations to the sound through a new conditioning procedure with repeated pairing of the sound to a positive stimulus. Episodic memories evoked by sounds, on the other hand, are presumably more amenable to a re-structuring and conscious reasoning about the previous event.

Much more could be said about the therapeutic implications of the new framework for musical emotions outlined in this chapter. However, even the simple examples above may go some way towards demonstrating that research on music and emotion might be useful also in our understanding of how *sounds* evoke pleasant and unpleasant emotions more generally. Hopefully, the present volume may help to motivate further collaboration among researchers and practicians in this important endeavor.[2]

2 This research was supported by the Swedish Research Council.

References

Adolphs, R. (2002). Neural systems for recognizing emotion. *Current Opinion in Neurobiology, 12,* 169-177.

Adolphs, R., Damasio, H., & Tranel, D. (2002). Neural systems for recognition of emotional prosody: A 3-D lesion study. *Emotion, 2,* 23-51.

Altshuler, I. M. (1954). The past, present and future of music therapy. In E. Podolsky (Ed.), *Music therapy* (pp. 24-35). New York: Philosophical Library.

Band, J. P., Quilter, S. M., & Miller, G. M. (2001-2002). The influence of selected music and inductions on mental imagery: Implications for practitioners of Guided Imagery and Music. *Journal of the Association for Music and Imagery, 8,* 13-33.

Bauer Afredson, B., Risberg, J., Hagberg, B., & Gustafson, L. (2004). Right temporal lobe activation when listening to emotionally significant music. *Applied Neuropsychology, 11,* 161-166.

Baumgartner, H. (1992). Remembrance of things past: Music, autobiographical memory, and emotion. *Advances in Consumer Research, 19,* 613-620.

Berlyne, D. E. (1971). *Aesthetics and psychobiology.* New York: Appleton Century Crofts.

Blair, M. E., & Shimp, T. A. (1992). Consequences of an unpleasant experience with music: A second-order negative conditioning perspective. *Journal of Advertising, 21,* 35-43.

Blonder, L. X. (1999). Brain and emotion relations in culturally diverse populations. In A. L. Hinton (Ed.), *Biocultural approaches to the emotions* (pp. 275-296). Cambridge, UK: Cambridge University Press.

Blood, A. J., & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of National Academy of Sciences, 98,* 11818-11823.

Blood, A. J., Zatorre, R. J., Bermudez, P., & Evans, A. C. (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature Neuroscience, 2,* 382-387.

Bonny, H. L., & Savary, L. M. (1973). *Music and your mind.* New York: Station Hill.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex. *Trends in Cognitive Sciences, 8,* 539-546.

Brown, C. M., Hagoort, P., & Kutas, M. (2000). Postlexical integration processes in language comprehension: Evidence from brain-imaging research. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (2nd ed.). (pp. 881-895). Cambridge, MA: MIT Press.

Brown, S., Martinez, M. J., & Parsons, L. M. (2004). Passive music listening spontaneously engages limbic and paralimbic systems. *Neuroreport, 15,* 2033-2037.

Buchanan, T. W., Lutz, K., Mirzazade, S., Specht, K., Shah, N. J., Zilles, K., & Jäncke, L. (2000). Recognition of emotional prosody and verbal components of spoken language: An fMRI study. *Cognitive Brain Research, 9,* 227-238.

Budd, M. (1985). *Music and the emotions. The philosophical theories.* London: Routledge.

Bunt, L., & Hoskyns, S. (Eds.). (2002). *The handbook of music therapy.* London: Routledge.

Cabeza, R., & Nyberg, L. (2000). Imaging cognition II: An empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience, 12,* 1-47.

Cancelliere, A. E. B., & Kertesz, A. (1990). Lesion localization in acquired deficits of emotional expression and comprehension. *Brain and Cognition, 13,* 133-147.

Caplan, D., Alpert, N., & Waters, G. (1998). Effects of syntactic structure and propositional number on patterns of regional cerebral blood flow. *Journal of Cognitive Neuroscience, 10,* 541-542.

Carlsen, J. C. (1981). Some factors which influence melodic expectancy. *Psychomusicology, 1,* 12-29.

Charlot, V., Tzourio, N., Zilbovicius, M., Mazoyer, B., & Denis, M. (1992). Different mental imagery abilities result in different regional cerebral blood flow activation patterns during cognitive tasks. *Neuropsychologia, 30,* 565-580.

Damasio, A. R., Grabowski, T. J., Bechara, A., Damasio, H., Ponto, L. L. B., Parvizi, J., & Hichwa, R. D. (2000). Subcortical and cortical brain acitivity during the feeling of self-generated emotions. *Nature Neuroscience, 3,* 1049-1056.

Davidson, R. J. (1995). Celebral asymmetry, emotion, and affective style. In R. J. Davidson & K. Hugdahl (Eds.), *Brain asymmetry* (pp. 361-387). Cambridge, MA: MIT Press.

De Houwer, J., Baeyens, F., & Field, A. P. (2005). Associative learning of likes and dislikes: Some current controversies and possible ways forward. *Cognition & Emotion, 19,* 161-174.

De Houver, 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,* 853-869.

Diaz, E., Ruiz, G., & Baeyens, F. (2005). Resistence to extinction of human evaluative conditioning using a between-subjects design. *Cognition & Emotion, 19,* 245-268.

Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research, 91,* 176-180.

Dowling W. J., & Harwood, D. L. (1986). *Music cognition.* New York: Academic Press.

Fanselow, M. S., & Poulos, A. M. (2005). The neuroscience of mammalian associative learning. *Annual Review of Psychology, 56,* 207-234.

Farah, M. J. (2000). The neural bases of mental imagery. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (2nd ed.). (pp. 965-974). Cambridge, MA: MIT Press.

Gabrielsson, A. (2001). Emotions in strong experiences with music. In P. N. Juslin & J. A. Sloboda (Eds.), *Music and emotion: Theory and research* (pp. 431-449). New York: Oxford University Press.

Ganis, G., Thompson, W. L., Mast, F., & Kosslyn, S. M. (2004). The brain's mind images: The cognitive neuroscience of mental imagery. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (3rd ed.). (pp. 931-941). Cambridge, MA: MIT Press.

Gärdenfors, P. (2003). *How homo became sapiens: On the evolution of thinking.* New York: Oxford University Press.

George, M., Parekh, P., Rosinsky, N., Ketter, T., Kimbrell, T., Heilman, K., Herscovitch, P., & Post, R. (1996). Understanding emotional prosody activates right hemisphere regions. *Archives of Neurology, 53,* 665-670.

Goldenberg, G., Podreka, I., Steiner, M., Franzén, P., & Deecke, L. (1991). Contributions of occipital and temporal brain regions to visual and acoustic imagery: A SPECT study. *Neuropsychologia, 29,* 695-702.

Gosselin, N., Samson, S., Adolphs, R., Noulhiane, M., Roy, M., Hasboun, D., Baulac, M., & Peretz, I. (2006). Emotional responses to unpleasant music correlate with damage to the parahippocampal cortex. *Brain, 129,* 2585-2592.

Hatfield, E., Cacioppo, J. T., & Rapson, R. L. (1994). *Emotional contagion.* New York: Cambridge University Press.

Johnsrude, I. S., Owen, A. M., White, N. M., Zhao, W. V., & Bohbot, V. (2000). Impaired preference conditioning after anterior temporal lobe resection in humans. *Journal of Neuroscience, 20,* 2649-2656.

Joseph, R. (2000). *Neuropsychiatry, neuropsychology, clinical neuroscience.* New York: Academic Press.

Juslin, P. N., & Laukka, P. (2003). Communication of emotions in vocal expression and music performance: Different channels, same code? *Psychological Bulletin, 129*, 770-814.

Juslin, P. N., Liljeström, S., Västfjäll, D., Barradas, G., & Silva, A. (2008). Emotional reactions to music in everyday life: Music, listener, and situation. *Emotion, 8, 668-683.*

Juslin, P. N., & Sloboda, J. A. (Eds.). (2001). *Music and emotion: Theory and research.* New York: Oxford University Press.

Juslin, P. N., & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioral and Brain Sciences 31,* 559-575.

Kinomura, S., Larsson, J., Gulyás, B., & Roland, P. E. (1996). Activation by attention of the human reticular formation and thalamic intralaminar nuclei. *Science, 271,* 512-515.

Koelsch, S. (2005). Investigating emotion with music: Neuroscientific approaches. *Annals of the New York Academy of Sciences, 1060,* 412-418.

Koelsch, S., Fritz, T., von Cramon, D. Y., Müller, K., & Friederici, A. D. (2006). Investigating emotion with music: An fMRI study. *Human Brain Mapping, 27,* 239-250.

Koelsch, S., Schroger, E., & Gunter, T. C. (2002). Music matters: Preattentive musicality of the human brain. *Psychophysiology, 39,* 38-48.

Lane, R. D. (2000). Neural correlates of conscious emotional experience. In R. D. Lane & L. Nadel (Ed.), *Cognitive neuroscience of emotion* (pp. 345-370). New York: Oxford University Press.

LeDoux, J. (2000). Cognitive-emotional interactions: Listen to the brain. In R. D. Lane & L. Nadel (Ed.), *Cognitive neuroscience of emotion* (pp. 129-155). New York: Oxford University Press.

Lerdahl, F., & Jackendoff, R. (1983). *A generative theory of tonal music.* Cambridge, MA: MIT Press.

Levenson, J. (1997). Emotion in response to art. In M. Hjort & S. Laver (Eds.), *Emotion and the arts* (pp. 20-34). New York: Oxford University Press.

Lundqvist, L.-O., Carlsson, F., Hilmersson, P., & Juslin, P. N. (2009). Emotional responses to music: Experience, expression, and physiology. *Psychology of Music, 37, 61-90.*

McKinney, C. H., Antoni, M. H., Kumar, M., Tims, F. C., & McCabe, P. M. (1997). Effects of Guided Imagery and Music (GIM) therapy on mood and cortisol in healthy adults. *Health Psychology, 16,* 390-400.

McKinney, C. H., & Timms, F. C. (1995). Differential effects of selected classical music on the imagery of high versus low imagers: Two studies. *Journal of Music Therapy, 32,* 22-45.

Maess, B., Koelsch, S., Gunter, T. C., & Friederici, A. D. (2001). Musical syntax is processed in Broca's area: A MEG study. *Nature Neuroscience, 4,* 540-545.

Menon, V., & Levitin, D. J. (2005). The rewards of music listening: Response and physiological connectivity of the mesolimbic system. *Neuroimage, 28,* 175-184.

Meyer, L. B. (1956). *Emotion and meaning in music.* Chicago: Chicago University Press.

Meyer, L. B. (2001). Music and emotion: distinctions and uncertainties. In P. N. Juslin & J. A. Sloboda (Eds.), *Music and Emotion: Theory and Research* (pp. 309-337). New York: Oxford University Press.

Murphy, F. C., Nimmo-Smith, I., & Lawrence, A. D. (2003). Functional neuroanatomy of emotions: a meta analysis. *Cognitive, Affective, & Behavioral Neuroscience, 3,* 207-233.

Neumann, R., & Strack, F. (2000). Mood contagion: The automatic transfer of mood between persons. *Journal of Personality and Social Psychology, 79,* 211-223.

Nyberg, L., McIntosh, A. R., Houle, S., Nilsson, L.-G., & Tulving, E. (1996). Activation of medial-temporal structures during episodic memory retrieval. *Nature, 380,* 715-717.

Osborne, J. W. (1980). The mapping of thoughts, emotions, sensations, and images as responses to music. *Journal of Mental Imagery, 5,* 133-136.

Panksepp, J. (1998). *Affective neuroscience.* New York: Oxford University Press.

Patel, A. D. (2003). Language, music, syntax, and the brain. *Nature Neuroscience, 6,* 674-681.

Phan, K. L., Wager, T., Taylor, S. F., & Liberzon, I. (2002). Functional neuroanatomy of emotion: A meta analysis of emotion activation studies in PET and fMRI. *NeuroImage, 16,* 331-348.

Quittner, A., & Glueckhauf, R. (1983). The facilitative effects of music on visual imagery: a multiple measures approach. *Journal of Mental Imagery, 7,* 105-120.

Razran, G. (1954). The conditioned evocation of attitudes: cognitive conditioning? *Journal of Experimental Psychology, 48,* 278-282.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27,* 169-192.

Sacchetti, B., Scelfo, B., & Strata, P. (2005). The cerebellum: Synaptic changes and fear conditioning. *The Neuroscientist, 11,* 217-227.

Schacter, D. L., Alpert, N. M., Savage, C. R., Rauch, S. L., & Alpert, M. S. (1996). Conscious recollection and the human hippocampal formation: Evidence from positron emission tomography. *Proceedings of the National Academy of Science, 93,* 321-325.

Sloboda, J. A. (1992). Empirical studies of emotional response to music. In M. Riess-Jones & S. Holleran (Eds.), *Cognitive bases of musical communication* (pp. 33-46). Washington, DC: American Psychological Association.

Steinbeis, N., Koelsch, S., & Sloboda, J. A. (2006). The role of harmonic expectancy violations in musical emotions: Evidence from subjective, physiological, and neural responses. *Journal of Cognitive Neuroscience, 18,* 1380-1393.

Stromswold, K., Caplan, D., Alpert, N., & Rauch, S. (1996). Localization of syntactic comprehension by positron emission tomography. *Brain and Language, 52,* 452-473.

Thompson, R. F. (2005). In search of memory traces. *Annual Review of Psychology, 56,* 1-23.

Tillman, B., Janata, P., & Bharucha, J. J. (2003). Activation of the inferior frontal cortex in musical priming. *Cognitive Brain Research, 16,* 145-161.

Tranel, D. (2000). Electrodermal activity in cognitive neuroscience: Neuroanatomical and neuropsychological correlates. In R. D. Lane & L. Nadel (Ed.), *Cognitive neuroscience of emotion* (pp. 192-224). New York: Oxford University Press.

Tucker, D. M, & Frederick, S. L. (1989). Emotion and brain lateralization. In H. Wagner et al. (Eds.) *Handbook of social psychophysiology* (pp. 27-70). Chichester, UK: Wiley and Sons.

Tulving, E. (1983). *Elements of episodic memory.* Oxford, UK: Oxford University Press.

Västfjäll, D. (in press). Affective reactions to sounds without meaning. *Cognition & Emotion.*

Waterman, M. (1996). Emotional responses to music: Implicit and explicit effects in listeners and performers. *Psychology of Music, 24,* 53-67

Correspondence should be addressed to
Dr. Patrik N. Juslin, Department of Psychology, Uppsala University, Box 1225, SE – 751 42 Uppsala, Sweden,
e-mail: patrik.juslin@psyk.uu.se

Auditory Problems

- Not only an Issue of Impaired Hearing

Ulf Rosenhall

Department of Audiology, Karolinska University Hospital, and Karolinska Institutet, Department of Clinical Neuroscience, Section of ENT and Hearing, Stockholm, Sweden

Introduction

The auditory system is phylogenetically a very old sensory system. It provides information for environmental orientation, and serves as a warning system. The vision is the most important sensory system for orientation, but hearing has a complementary function. The auditory system scans the surrounding landscape in all directions, day and night, and in terrain where the view is blocked. For this purpose the auditory system must be able to detect short, deviant sounds in a background of ambient noise. Moreover, the auditory system has a very accurate directional hearing, above all in the horizontal plane. The sound localisation process is based on dichotic hearing, a fusion of auditory input from both ears. Minor differences of arrival time, phase, and intensity of sounds between the two ears is the physiological basis for directional hearing.

The most important function of the auditory system for us is communication. Hearing constitutes the afferent branch of oral communication, which is the fundament of social contacts. The ability to develop spoken language in early childhood is dependent on normal hearing. The presence of hearing impairment, even of moderate extent, is detrimental on the development of a language. The auditory system must be able to detect and register subtle and rapidly changing patterns of the speech regarding frequency, intensity, and rhythm, often in the presence of ambient background noise. This on-line process represents a formidable challenge on perception, cognition and working memory. This process is executed on all levels of the auditory system.

Still another function of the auditory system is to provide aesthetical qualities: music is important to most persons, and we also appreciate sounds in the nature like bird song, the wind blowing in the canopy of a tree, and the sound of the sea on a beach. These sensory inputs give us refreshment and positive experiences.

Finally, after a day in our normal soundscape at work, and in leisure time, we need to relax in a quite surrounding at home.

Anatomy and physiology of the auditory system – a short summary

The auditory system has a peripheral part and a central part. The peripheral part is constituted by the external and middle ear, by the inner ear, and by the cochlear nerve. The central part consists by the auditory pathway, that starts in the pons, passes the midbrain, and ends in the cortex (Figure 1).

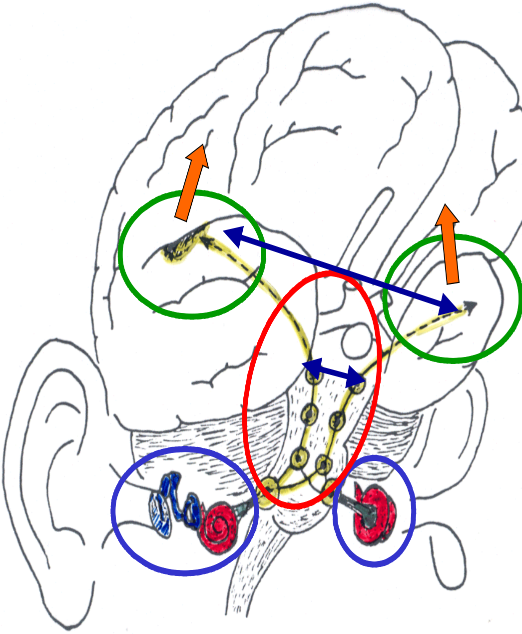

Figure 1. The peripheral part of auditory system consists of the external, middle and inner ear, and the cochlear nerve (blue ellipses). The central part of the auditory system consists of the auditory pathway (red ellipse), and cortical areas (green ellipses). There are connections to other cortical areas and commissural connections between the hemispheres.

The outer part of the ear consists of the external ear and canal, the tympanic membrane and the middle ear with the three ossicles. Sound waves are conveyed from the air to the inner ear by this passive, mechanical sound transmitting system. It provides and amplification of 30 dB, and by this mechanisms a physical obstacle is overcome when air borne sound waves are transformed to sound waves in the peri- and endolymph fluids in the cochlea in the inner ear.

The cochlea is the sense organ where the mechanical energy of the sound waves are transformed to nerve impulses by approximately 15 000 hair cells. One single row of inner hair cells (IHCs) are mechanoreceptors. Three rows of outer hair cells (OHCs) modulate the sensitivity of the cochlea, and sharpen the frequency discrimination.

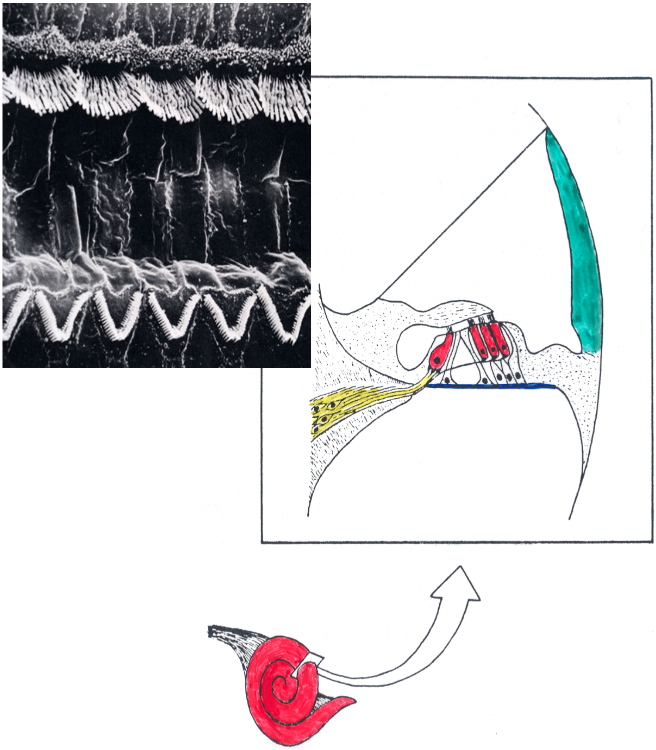

Figure 2. The cochlea with the sense organ, the organ of Corti. There are two types of hair cells, IHCs in one row, and OHCs in three rows. The hair bundles of the IHCs are slightly curved (upper row in the photomicrograph), and W-shaped in the OHCs (lower row).

An active, nonlinear process in the cochlea is mediated by the OHCs, and facilitates the perception of the complex sound patterns in speech. These patterns are characterized by rapid sound variations combined with slow modulations caused by speech syllables, words and intonation. Weak sounds, otoacoustic emissions (OAEs), are generated in the normal cochlea, and they reflect the active, motile function of the OHCs.

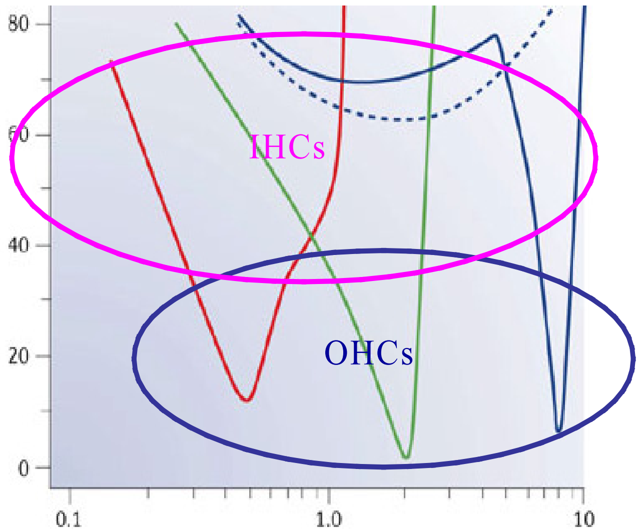

Figure 3. Different functions of the IHCs and OHCs. The IHCs function at a moderately intense levels and can perceive complex sound patterns. The OHCs sharpens the frequency discrimination.

Every hair cell has a hair bundle, consisting of about 100 kinocilia (Figure 2). At the base of the hair cell there are synaptic nerve endings from the first auditory neuron. 85 – 90% of all afferent neurons (in all about 30 000) form synaptic contact to the IHCs. A few hundred efferent nerve fibers from the brain stem make synaptic contacts to the OHCs and mediate a modulating function from the brainstem to the cochlea as an efferent regulatory system (MOC).

The central auditory system (CAS) consists of the auditory pathway, with nerve tracts and nuclei, starting at the entrance of the cochlear nerve in the pons, and passes the midbrain and subcortical areas. In the cortex there are primary, secondary and tertiary cortical areas. Commissural connections between the hemispheres are present at all levels of the auditory system from the brainstem to the corpus callosum (Figure 1).

Impairments of threshold hearing and of speech perception

When we are talking about auditory problems we most often think of hearing impairment (HI). The presence of a HI means that the sounds within a specific frequency range are not perceived when they are presented at an intensity level heard by a normal functioning ear. The range and extend of a HI can is measured with a "conventional" hearing test, the pure tone audiogram. A HI can be of a very variable extent, from mild to profound up to total deafness, when the ear cannot hear any sounds, even at intense levels. The frequency range affected also varies. In the most common types HI the high frequencies are affected more severely than the low frequencies.

The speech perception is often disturbed, in most instances in connection to a HI. High frequency HI compromises the perception of many consonants, with disturbed speech perception as a result. It is considerably easier to hear speech in quiet than in background noise. Without disturbing noise the capacity to hear monosyllables is remarkably intact in cases with mild to moderate high frequency HI, but at a certain level of HI the speech perception collapses (Figure 4). In background noise a person with even mild high frequency HI has difficulties to hear monosyllables, and the situation becomes still worse if the hearing impairment worsens (Figure 4).

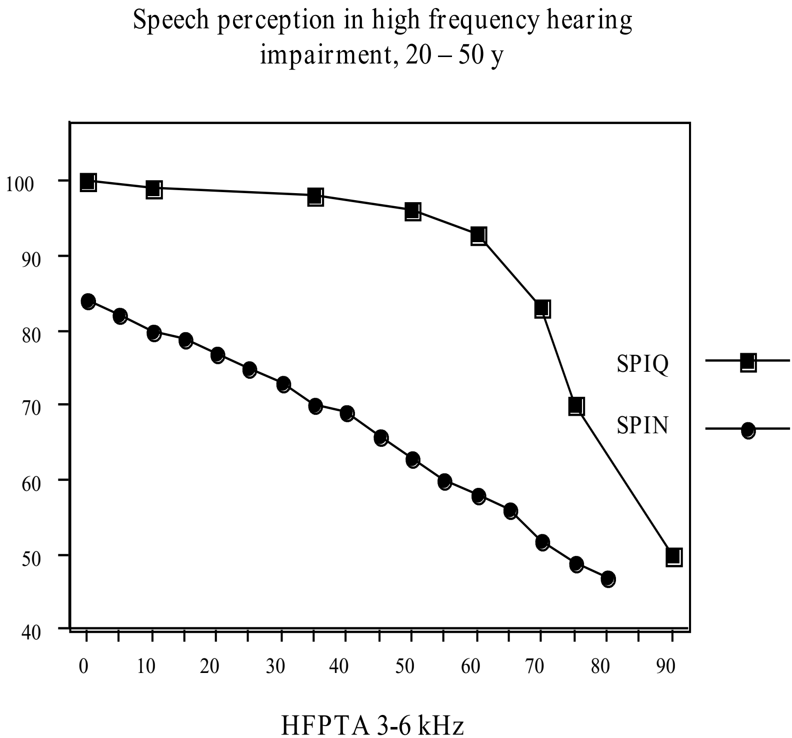

Figure 4. Speech perception (in percent) for monosyllabic words in quiet (SPIQ) and in background noise (SPIN), adults aged 20 to 50 years. The effect of high frequency hearing impairment is shown in the figure. The average threshold elevation of the frequencies 3, 4 and 5 kHz is shown on the X-axis. Normal hearing to the left, severe hearing impairment to the right. In average, an ear with normal hearing perceives 100% of the words in quiet, and about 85% of the words in noise. High frequency HI reduces the speech perception, especially in the SPIN-situation. The data have been collected from Lidén, 1954 (SPIQ); Magnusson, 1996; Barrenäs& Wikström, 2000 (SPIN).

Many patients with normal pure tone audiograms have difficulties to perceive speech in relatively mild background noise (King-Kopetzky syndrome). The causes of this syndrome remains unknown in most instances, and might vary from psychogenic – stress related, to disturbances of the CAS. In some instances the efferent MOC system is not functioning properly.

A small group of patients with auditory neuropathy (AN) have extreme difficulties to perceive speech in quiet. These patients can hear sounds, but they cannot understand speech, that sounds totally blurred to them. The impairments in AN are complicated and poorly understood. It has been suggested that there can be selective IHC-loss, synaptic disturbances, and lesion of the cochlear nerve. The OHC function is normal in AN.

Tinnitus

Tinnitus is defined as a sensation of a sound, or sounds, in one or in both ears, or inside the head, such as buzzing, ringing, or whistling, occurring without an external stimulus. Tinnitus is a symptom, not a diagnose, and the causes of tinnitus vary. In many instances tinnitus is related to a concomitant HI. The peripheral lesion triggers changes of the neural input to the CAS, that activates unimpaired cortical and subcortical auditory centres. Severe tinnitus is common in profound hearing impairment and total deafness, and is regarded as a phantom sensation.

Tinnitus retraining therapy is a specific clinical method based on the neurophysiological model of tinnitus that involves the limbic system and the autonomic nervous system (Jastreboff, 2007). The method is aimed at habituation of reactions evoked by tinnitus, and subsequently habituation of the tinnitus perception. One part of the method is sound therapy, aimed at weakening tinnitus-related neuronal activity.

Other explanatory models of tinnitus are ion channel dysfunction of IHCs, impaired gate control, and ephatic transmission, "cross-talk" between nerve fibres, are other models for the generation of tinnitus (Holgers & Barrenäs, 2003). The gate control theory of pain is a model to that of sound, and hypothesizes that physical pain is not just a direct result of activation of pain receptor neurons, but is rather modulated by interaction between different neurons.

There is also a somatosensory model, in which non-auditory neural input triggers tinnitus (Shore & Zhou, 2006). These patients have most often normal hearing, measured with pure tone audiometry.

Other auditory symptoms, paracuses

Paracuses encompass a variety of disturbances of auditory perception (Hinchcliffe, 2003). Sound intolerance constitutes one important group. Hyperacusis is defined as abnormal intolerance for every-day sounds. Hyperacusis is often seen in without any deterioration of hearing sensitivity. A common cause of hyperacusis is exposure to loud noise. Phonophobia, fear of sounds, is an extreme and very disabling variant of hyperacusis, and is often present together with psychiatric conditions. Misophonia is intolerance to specific sounds. Very little is known about neurophysiological models causing sound intolerance. Dysfunction of the efferent systems (one is the MOC-system) has been proposed, as well as abnormal gate control. Autophonia is intolerance to the subject'sown voice. The condition has been related to patulous Eustachian tube caused by abnormal muscular activity.

Recruitment of loudness is a non-linear increase of loudness, seen in cochlear hearing impairment. The patient has a sensorineural hearing impairment, and suprathreshold sounds, even at levels that are fairly close to the thresholds, are disturbingly loud. The condition is seen in OHC-degeneration, and the reception of sounds of mild to moderate intensity is impaired (Figure 3). When the intensity reaches the level where the tuning curves are flattened (the domain of IHC-hearing), the reception of sounds reaches the normal level within a narrow increase of intensity. The dynamic range of loudness, from threshold to an uncomfortable level, is decreased. Recruitment should not be labelled as hyperacusis.

Sound distortion can refer to abnormal non-linear affects of the inner ear. The most common distortion is diplacusis, which is a frequency related disturbance in which a single tone is heard as two tones of different pitch in one ear, or in the two ears. It is a typical phenomenon of Ménière's disease.

Disturbed directional hearing causes no or only minor problems in most situation. However, accurate sound localisation is useful in traffic situation and to localise a person in a crowded place.

Conclusions

Hearing impairment is only one manifestation of lesions within the auditory system. Other symptoms are problems to hear speech in noise, tinnitus, hyperacusis and other phenomena related to intolerance to sounds, sound distortion, and diplacusis (Figure 5). These manifestations of auditory lesions and symptoms occur often in combinations. Lesions, diseases and disorders are most common in the peripheral part of the auditory system,

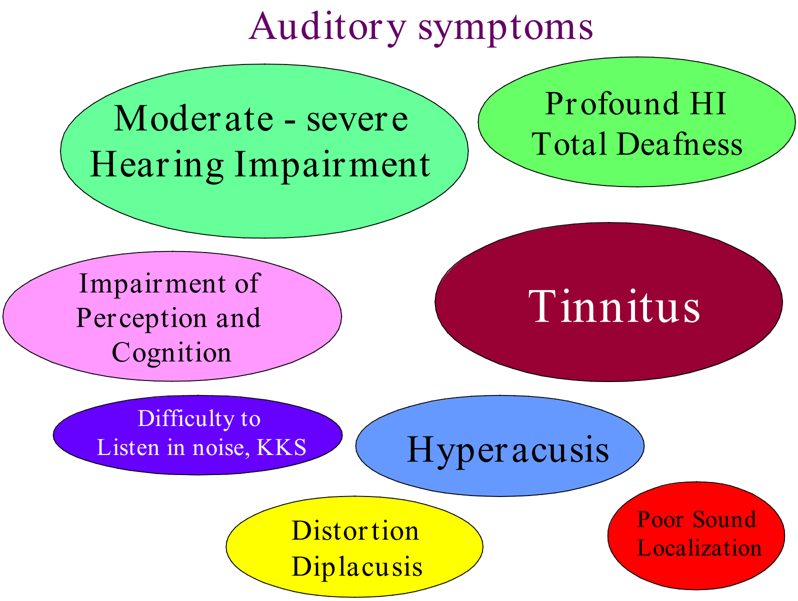

Figure 5. There is a variety of auditory symptoms, often occurring in various combinations.

References

Barrenäs ML, Wikström I. The influence of hearing and age on speech recognition scores in noise in audiological patients and in the general population. Ear Hear 21, 569-77, 2000

Hinchcliffe R. In: Textbook of Audiological Medicine. Clinical Aspects of Hearing and Balance (eds: LM Luxon, JM Furman, A Martini, D Stephens). Taylor & Francis Group, London, pp. 579-91, 2003

Holgers KM, Barrenäs ML. The pathophysiology and assessment of tinnitus. In: Textbook of Audiological Medicine. Clinical Aspects of Hearing and Balance (eds: LM Luxon, JM Furman, A Martini, D Stephens). Taylor & Francis Group, London, pp. 555-69, 2003

Jastreboff PJ. Tinnitus retraining therapy. Prog Brain Res 166, 415-23, 2007

Lidén G. Speech audiometry. Arch Otolaryngol Suppl 89, 399-403, 1954

Magnusson L. Predicting the speech recognition performance of elderly individuals with sensorineural hearing impairment. A procedure based on the Speech Intelligibility Index. Scand Audiol 25, 215-22, 1996

Shore SE, Zhou J. Somatosensory influence on the cochlear nucleus and beyond. Hear Res 216-217, 90-9, 2006

The Role of Psychoacoustics for the Research on Neuropsychiatric States

Theoretical basis of the S-Detect method

by

Sören Nielzén, Olle Olsson, Johan Källstrand and Sara Nehlstedt

Introduction

Sound is constituted by air borne pressure waves. A completely regular simple form is the sinus wave. This may vary in its excursions – amplitude variations - thereby representing higher or lower energy.

It may further have shorter or longer periods, which represent wave frequencies. The sinus waves of many separate frequencies may gather to a more complex pressure wave, which then contains a sound spectrum of frequencies.

The spectra get different contours when the separate frequencies are depicted side by side along an abscissa. Such pictures describe what is called frequency envelopes.

Two sinus tones may have exactly the same amplitude maxima and minima in time during their propagation through the air. They are in phase. Displacements between two waves may appear in any angle within the period. Phases and amplitudes may as well be depicted with regard to their envelopes in time. The sound wave contains the basic structure for communication, but the communication functions only thanks to the analyzing powers of the various detection systems in machines, animals and humans. Combinations of the basic sound parameters create endless variations of sound perceptions. In humans, the combinations importantly serve the reception of speech and have an almost equally appreciated value in music[1].

Clinical aspects

In the following an abbreviated description will be made on the analyzing systems in the auditory pathway and on psychoacoustic phenomena used to reveal various aspects of them. Such descriptions help to clarify the complexity of stimulus-response relations and make one better understand implications for perception, cognition and other psychological effects.

Sound experiences become different when some neuropsychiatric disturbance overshadows the natural neurophysiological and mental system. The aim of this article is to expose the use of psychoacoustics and neurophysiology to demonstrating aberrances of the function within the auditory system in schizophrenia and ADHD.

Sounds in experiments

The elements of sound have been studied by comparisons which have been registered by sophisticated, often statistical methods such as discriminant ratings, forced-choice techniques etc. Regarding frequency and sound pressure it is found that albeit - like for all senses - they are processed in a logarithmical manner, they are further non-linear due to greater discriminant sensitivity for high pitched tones and medium loud sounds. The logarithmic scales have to be corrected into scales of subjective perception. These are called the mel-scale for pitch and sone-scale for loudness. Distances in pitch and sound pressure are measured in Mel and dB (decibel). The human ear is extremely sensitive for pitch changes and has a very low threshold for sound pressure (10^{-12} Watt/cm^2). It should be noted, that pitch and loudness are perceptual conceptions, subject to reciprocal interactions and influences. This means that a tone may be higher or lower when combined with different sound pressures[2].

Spectrum of many frequencies may be depicted in sonagrams, i.e. graphic lines with the ordinate representing frequencies and the abscissa giving time. Complex sounds have a fundamental, which is the dominating, regular – often the lowest – tone, and partials, which arise by even and/or un-even parts of a sounding string or pillar of air. In speech experiments one talks of formants as corresponding to the partials of musical sounds. The combination of the fundamentals and two formants and their relative sound pressure defines the vowels in speech, and fundamentals and partials in music make voices and instruments characteristic. Any complex sound is perceived as having a fundamental – it is appointed one by the ear – even if there exists no fundamental from an acoustic definition. It is worth mentioning that all natural sounds are complex and that the sinus tone case is an exception. Further, the ear constructs sound itself and emits it from the ear-drum. As mentioned, the central nervous system similarly constructs a fundamental when specific partials are sounding, and we perceive this as a tone (periodic pitch, Tartini pitch, musical pitch, virtual pitch, organ fundamental)[3].

Psychoacoustic stimuli

Zwicker tones are produced by presenting a white noise that has a hole in it, i.e. a small range of frequencies is lacking somewhere in the middle of the spectrum. When a subject is stimulated with it for a while (30 seconds) and the stimulus then is stopped, he or she will start to hear a tone corresponding to the hole. This is a psychoacoustic after-effect, which is well known to psycho-physiologists for other sensory modalities too. After-effects vary with psychiatric conditions and are therefore valuable in the development of test methods[4].

Another stimulus dealing with noise in the auditory system is *gap detection.* A noise is presented followed by silence (the gap), thereafter the noise continues again. When the gap is sufficiently short, the subject perceives a continuous sound. The normal threshold for this is normally less than 20 msec of silence duration. Longer thresholds indicate midbrain lesions (as in aging)[5].

Masking denotes the hearing of one sound in the presence of another. Commonly, noise is used to "cover" a tone and this may be done simultaneously, forward in time or backward in time in relation to the tone. It is used to study dissolution of time and frequency in hearing. By means of moving the masker to the sides of the tone (within the frequency domain), one has assessed regions and cell populations that are tuned to sharper perceiving of pitch-heights. In this way critical bands for frequency perception have been defined[6]. These are centered automatically on the pitch that first arrives at the ear – they are so called dynamic filters.

If any component of the noise in masking experiments is shared by the stimulus tone, such as amplitude modulation (tremolo in music) or frequency modulation (vibrato in music) "release of masking" occurs. Investigations of thresholds for this are valuable to shed light of specific problems. Binaural (both ears) or dichotic (one stimulus in one ear and another in the other) stimulation is used for research on specific questions related to directional hearing, changes of thresholds and effects on perception.

Disturbance of simultaneous masking is related to dysfunctions of peripheral structures of the hearing system while forward and backward masking point to dysfunctions of the central nervous system[7].

Not only noise may be used to demonstrate *suppression* of reactions to sounds. A tone in presence with another is suppressed, less clearly heard. *Two tone suppression* is used experimentally in neurophysiological experiments e.g. to assess inhibition in neural networks and of cells[8].

Virtual pitch is an interesting psychophysical phenomenon with importance for clearer hearing. When aliquots are added to a dull sounding 16 feet bass voice of the organ, the bass sound is heard very clearly and distinctly. The bass sound may be heard even without any bass pipe sounding. This mechanism evidently serves some function of sound detection within the hearing system. It was originally supposed to be a result of unresolved (the auditory system resolves a complex sound into its partial pitch components) parts of the pitch processing in the auditory pathway[9], but has later been proposed to be a more central process based on resolved harmonics in the nervous system[10]. The virtual pitch is computed by the central nervous system's pitch processors, thereby integrating binaural fusion, when accurate[11]. Virtual pitch constitutes a possible stimulus for neuropsychiatric studies.

The resolution of pitches is a complex process influenced by the mass of elements of the incoming stimulus. This may be examplified by the "pitch paradoxes" investigated by Diana Deutsch[12]. She demonstrated that pitch judgments of ascending or descending tones are influenced by different factors such as proximity of tones and spectral envelopes.

Still more complicated may the sound experience be when binaural mechanisms are involved. The *precedence effect* offers such an example. In an experiment where two clicks are delayed between the two ears, they will be perceived as one click sound coming from the side of the first arriving click. If the time between them is more than 12 ms, two sounds will be heard and if it is 2 msec or less, only one sound is perceived and interpreted as coming from a central position in the auditory field. Preliminary experimental results indicate that this mechanism is dysfunctional in schizophrenia[13].

Psychoacoustic phenomena are not only advantageous to study in connection with instantaneous events and elementary aspects of sound. On the contrary, when discontinuous sounds with broad frequency spectra dispersed in patterns are used as stimuli, many possibilities of ambivalent interpretations arise that may lead the listener in diverse directions. This is due to the fact that so called features are created by means of cross-correlations at high levels in the central nervous system. In the owl, localization e.g., is computed in the form of a map in the matrix of cells in the superior colliculi, and the owl reacts to its prey according to combined visual and auditory cues represented as "feature" in neural activity [14]. Humans have similar preformed neural systems in relation to syllables and linguistic sounds[15]. Complex stimulation may contain elements that elicit features which mislead the listener and in this way auditory illusions occur.

Consider consecutive tones played very slowly. You hear the tones one by one. Played a bit faster you suddenly perceive a melody. When played very fast and with broad intervals, voices will come up and at extreme speeds mixtures of tones and noise seem to exist. That the perceptual apparatus organizes the sound material in different percepts means that different "streams" are formed. *Streaming* is the psychological term for the appearance of e.g. voices in a composition. The conditions for the formation of streams to show have been formulated by Albert Bregman in his monograph Auditory Scene Analysis from 1990[16].

Olle Olsson[17] used streaming in his investigations on persons with schizophrenia and found that clear aberrances of perception of streaming were connected with the disorder. This was true even for the *continuity illusion*, which may arise in loud environments and means that the brain reconstructs missing sounds. This makes it possible to hear a single message in a noisy party; therefore it is sometimes called "the cocktail party effect". Persons with schizophrenia further showed aberrances when compared with healthy subjects regarding *contralateral induction.* Contralateral induction refers to the motion of sounding objects in the environment. Localization is generally controlled by interaural time- and intensity differences between the two ears, but if e.g. spectral content is more or less identical most people will say that the sound comes from one defined sound source where the dominating spectrum is emitted, and not judge according to the time- and intensity difference cues. The process is analogous to when you see a person speak on the TV. You will hear his voice from his or her mouth, even if the loudspeaker is fairly far from the TV-set.

Neurophysiology

In order to understand the rationale for investigating neuropsychiatric states by auditory measures, a brief description of the principles of the neural functions of hearing is certainly helpful if not necessary.

The hearing system is built up by the receptor organ, the *cochlea*, and its nerve trajectories into the brain up to *cortex*. On the way to that location the signals pass main relay stations called nuclei. They are in order from bottom to top *cochlear nucleus, the olivary complex with trapezoid bodies, inferior colliculus* in the brain stem, and *medial geniculate body* in the thalamus.

In the cochlea an elastic structure called the *basilar membrane* fills the function of a sensory receptor. The sound waves become transformed to a liquid oscillation in the cochlea and due to the anatomical form of the basilar membrane and the cochlea, frequencies are spatially separated on different places of this receptor organ. Specific receptor cells, *hair cells*, transform the physical stimulation to electrical pulses which are transmitted to the *auditory nerve*. The spatial frequency representation is preserved among the *axons* (nerve fibers) of the auditory nerve, further through the whole of the pathway and even in cortex.

This example of representing different frequencies is a *code* which is fairly simple in comparison with the demands of the nerve functions for resolving most other tasks dealt with by the system. It must be recognized, that the auditory nervous system is highly differentiated. It contains cells that may fire up to at least 3000 times per second, while skin receptor cells are refractory during single decimal parts of seconds before next firing. Further, a multitude of specializations occur among auditory cells. Some are sensitive to frequency ranges, some to specific loudness ranges and some to *lateralization* (from which ear – side - signals come). There are cells that react to *features*, i.e. compound nerve processing at earlier stages in the pathway, representing e.g. calls among birds, linguistic or musical components among humans etc.

All these functions depend on anatomical specializations developed during the phylogenetic past. In the cochlear nucleus there are "bushy" cells that have trees of short *dendrites* (cell receptor branches) securing a phase constant transmission. Stellate cells on the other hand have longer dendrites, compound functions, and can signal with bursts containing variable spike numbers. Fusiform cells of the dorsal part of the nucleus have long dendrites which make them integrate signals and exert inhibition on the activity of other cells. Up to ten types of reaction patterns of single cells within the auditory system are known, such as "on, off, sustained, chopper, pauser", and so on.

The grouping of signals into features and finally percepts does seldom rely only on one coding principle. By inhibition, facilitation, integration and cross correlation a continuous refining of basic information takes place. Frequency is e.g. coded also in real time because the cells of the auditory nerve samples the periods of the sound wave. Together with neighboring cells they send a volley[18] with a correct continuous electrical picture of the frequency for which they are especially sensitive. At the same time they put each frequency in the same phase because they always fire in the raise portion of the stimulation from the hair cells. It is called *phase locking*. But this is not enough. While exerting these specialized functions they at the same time convey a code for loudness by changing the underlying general spike rate. Furthermore, they are –from systems higher up - subjected to control of the degree of synchrony among cell firing, which is a further instrument for refined coding of maybe pitch sharpening.

The mechanisms behind phase locking has generalized counterparts elsewhere. In the owl and bat for instance, locking to space cues occurs by "space specific" cells [19]. At higher levels a diffuse border between learning and *automatic grouping* (the subconscious perceptual counterpart of feature formation) exists, and there are many types of *feature locking* for natural sounds, harmonies, tones, linguistic word roots and so forth.

The olivary complex is designed to analyze directions of the incoming sounds. This is achieved by the phase-locked firing from the two sides. An interaural time difference results in different delays according to the angle in front of the head. The time difference is coded and space specific cells in colliculus inferior register an angle. Similarly an angle is coded for intensity difference between the ears, because the head shadows one of the sides more or less. For humans, this works in azimuth, but for positions in the vertical plane the frequency spectra from the two ears are compared since these spectra are different because of filtering in the two pinnae.

The space sensitive cells are organized in a spatial pattern, which is another principle of the function of the auditory system. As mentioned before, frequency is displayed in a topographical manner and so is loudness. Detector cells for various features – amplitude modulation frequency is an example [20] - are similarly organized in quasi circular patterns in the inferior colliculus, the medial geniculate body and the cortex. In this way spatial maps of frequency, amplitude, space and features are organized in separated planes, most clearly to be observed in the inferior colliculus. Time codes are converted to place (of the neuronal substrate) codes.

In the auditory *cortex* the mapping principle and the spatial organization is at hand. But both renewed parceling and integration occurs. Speech in bilingual persons is for example is processed at different locations for the two languages [21]. On the other hand, features are created by combination sensitive neurons which react on specific combinations of loudness and frequency, and of course on combinations of other parameters. A final percept arises only after fairly long times (parts of seconds). When auditory illusions are concerned this so called *build up* period may take up to five seconds, before the relevant information is made conscious to the listener. Finally, the main function of the cortex is the integration of auditory information by associative connections to vision, memory, thinking etc.

Preparatory studies

Auditory illusions and schizophrenia was studied at the Psychoacoustic Laboratory of the Psychiatric Clinic in Lund by Olle Olsson[22]. The aims of the studies were to assess aberrances of perception between persons with schizophrenia and healthy subjects. It was further anticipated that aberrances could perhaps be objectively assessed by contemporary objective measures within neurophysiology. This should in the end lead to the ultimate goal which was to offer an objective method as support for diagnostic and treatment controlling needs in psychiatry.

The aims were based on forthcoming evidence that schizophrenia is a neuropsychiatric state in its own right. It is documented since nearly a century that cortical degeneration occurs during the course of the disease, which explains the gradual deterioration of cognitive functions – the dementia – characteristic of the illness. This, however, seems to be a secondary process correlated with each psychotic exacerbation. Atrophic processes of cortical gray and white matter and microscopic cell abnormalities are demonstrated in several studies[23]. Disconnectivity between functional circuits has been assessed with Diffusion Tensor Imaging. Disruption of anatomical structures is compatible with clinical symptoms of discontinuity in perceiving, thinking, talking and smooth movements regularly observed as signs of the disease. From the experimental view it has been noted, that adaptation is not as effective in schizophrenia as in healthy states. The deshabituation, as it is called, applies to all senses and is an argument for theories of lacking filters in schizophrenia. Deficient "filters" are supposed to cause an undue increased influx of stimuli to the central nervous system, thereby causing chaos in mental processing.

Neurophysiological dysfunctions in prepsychotic states and within relatives of psychotic patients point towards the existence of trait markers of an elementary character. Thus, Freedman et al have documented abnormality of an electrophysiological brain wave after 50 ms post stimulus[24]. After 300 ms several studies have shown abnormalities of evoked auditory responses of the common electroencephalogram (EEG). Näätenen et al studied another characteristic of the EEG, the so called "mis-match negativity"[25]. This is a response which shows for healthy subjects after a short break in an otherwise continuous sound stimulation. Persons with schizophrenia show abnormal results in this examination. Green[26] has shown that visual masking does not function normally for schizophrenics as indeed Källstrand et al observed in connection with auditory masking.

A study by means of fMRI (functional Magnetic Brain-Imaging) with the use of a tonal streaming as stimulus was performed in Vienna 2001 – 2002[27]. The study was very elaborate and time-consuming and therefore only few patients could be measured at the cost and time given for the study. Far less did we reach the goal to include schizophrenic patients. However, a valuable finding was seen for those 3 patients who validly reported the hearing of streaming and were technically measured in a reliable manner. As seen from the figure 1 there is no activation of associative connections of the cortex. The processing of streaming appears to take place within networks within the brainstem, thalamus and up to the gyri of the temporal lobe. This fact supports a supposition made within psychology, that automatic grouping, such as streaming, is a genuine or primitive function without elements of any conscious processing.

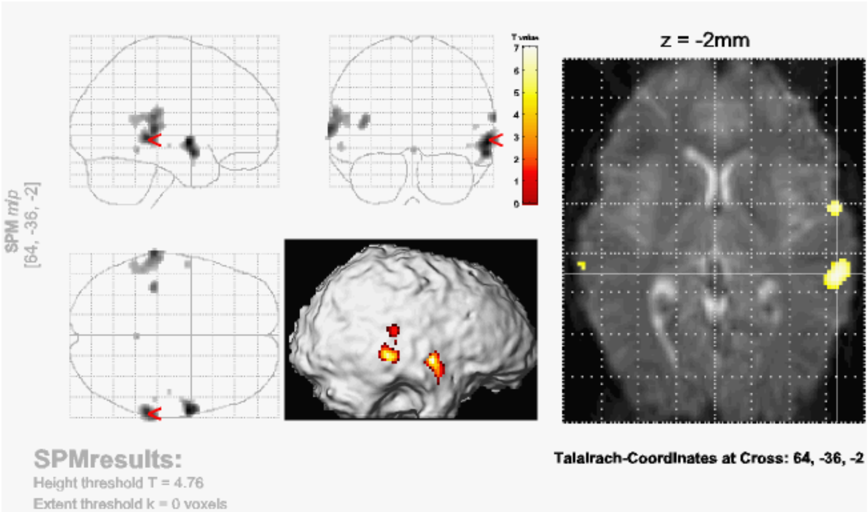

Figure 1: fMRI activation of streaming in a sample of healthy subjects tentatively showing, that streaming is mainly processed in subcortical generators and that it is not a process of associative cortical activity.

From the assertions related above it became logical to direct the attention to the brain stem in order to search for neurophysiological correlates with stimuli provoking automatic grouping in the nervous system.

A few postulates for the continuing work with auditory brain stem evoked response (see below!) were put forward:

Persons with schizophrenia harbor constitutional traits (neurophysiological markers) which make them susceptible to react with clinical signs of the schizophrenic disorder when exposed to releasing factors.

The fundamental pathological processes in schizophrenia may affect any part or parts of a sensory or motor system and are not localized at any spot in the nervous system.

The assessment of neurophysiological correlates must therefore rely on complex stimulation and complex measurements.

Analysis of differential measurements must take into account both general differences and systematic discrepancies related to single elements of the stimuli and the singular response patterns of the nuclei corresponding to the peaks and troughs of the ABR-waves.

There are several techniques available for investigating the functional state of the brain stem. For practical reasons the BERA (Brain stem Evoked Response Audiometry) also denoted ABR (Auditory Brain stem Response) was chosen. A number of different sounds were composed to serve as convenient triggers to target the earlier revealed weaknesses in the schizophrenic perception. The sounds were patented. Then, the stimuli and test parameters were organized to suit the technical requests of ABR-measurements as it is commonly used in audiology. When this had succeeded the testing of healthy subjects and persons with schizophrenia began. It has turned out that differences of the ABR-waves between the two groups reliably separate them from each other. As hypothesized, there is no simple differentiation between a non-specific stimulation and any certain peak or trough of the resulting brain wave. Differences are only discerned by sophisticated analysis of the waves regarding correlations with specific qualities of the diversified acoustic stimuli. The analysis was based on the huge amount of data acquired from the measurements and was accomplished through weighting of significant discrepancies. Results from our studies are in line with our hypotheses and postulates and the discrimination between groups of persons with schizophrenia and groups of healthy subjects is over 90 percent. Preliminary findings on ADHD seem to be very promising. The S-Detect method, an application of ABR for psychiatric use, has been developed in consequence with the studies. It is predicted to get an important role as a support within clinical psychiatry.

References

Everest, F.A.,Master Handbook og Acoustics. McGraw-Hill, New York 2001.

Nielzén, S., Olsson O., (Eds.) Structure and Perception of Electroacoustic Sound and Music. Elsevier Science Publishers.Amsterdam, 1989.

Rosen, S., Howell.P., Signals and Systems for Speech and Hearing. Academic Press, London 1999.

Franosch, J-M. et al., Zwicker Tone Illusion and Noise Reduction in the Auditory System. Physical Review Letters, vol.90, nr 17, p.178103-1 – 178103-3.

Fitzgibbons, P.J., & Gordon-Salant, S., Temporal Gap Resolution in Listeners with High-Frequency Sensoryneural Hearing Loss. J. Acoust.Soc. Am., 81, 133-137, 1987.

Fletcher, H., Auditory Patterns. Rev.Mod. Phys. 12:47-65.

Gutschalk, A. et al., Human Cortical Activity During Streaming Without Spectral Cues Suggests a General Neural Substrate for Auditory Stream Segregation. J. Neurosci. 2007 Nov 28;27(48):13074-81.

Källstrand, J., Montnémery, P., Nielzén, S., Olsson, O.Auditory masking experiments in schizophrenia. Psychiatry Res. 2002 Dec 15;113(1-2):115-25.

Shouten, J.F., The Perception of Subjective Tones. Proc., K. Ned. Akad. Wet., 41, 1086-1093.

Terhardt, E, Grubert, A., Factors Affecting Pitch Judgments as a Function of Spectral Composition. Percept Psychophys. 1987 Dec;42(6):511-4.

Pantev, C, Elbert, T., Ross, B., Eulitz C., Terhardt, E.,.Binaural Fusion and the Representation of Virtual Pitch in the Human Auditory Cortex.Hear Res. 1996 Oct;100(1-2):164-70.

Deutsch,.D., Some new Musical Paradoxes, in Nielzén,S., Olsson O., (Eds.) Structure and Perception of Electroacoustic Sound and Music. Elsevier Science Publishers.Amsterdam, 1989.

Fristedt Nehlstedt, S., A Study of the Precedence Effect in a Sample of Auditory Hallucinating Schizophrenics, Research Report for M.Sc., Dpt of Audiology, Lund University, 2004.

Knudsen, E. I., Experience Shapes Sound Localization and Auditory Unit Properties During Development in the Barn Owl. In Auditory Function, Neurobiological Bases of Hearing. Eds.: Edelman G.M., Gall W.E. and Cowan W. M., John Wiley and Sons, New York, 1985.

Mattingly, G. M. and Liberman, A. M., Specialized Perceiving Systems for Speech and Other Biologically Significant Sounds. In Auditory Function, Neurobiological Bases of Hearing. Eds.: Edelman G.M., Gall W.E. and Cowan W. M., John Wiley and Sons, New York, 1985.

Bregman, A. S., Auditory Scene Analysis. ”A Bradford Book”, MIT Press, Cambridge Mass., London, 1990.

Olsson, O., Psychoacoustics and Hallucinating Schizophrenics; A Psychobiological Approach to Schizophrenia. Thesis, Lund 2000.

Wever, E.G., Theory of Hearing, Wiley, New York, 1949.

Suga, N., Feature Extraction in the Auditory System of Bats. In Basic Mechanisms in Hearing Møller, ed., pp. 675-744, Academic, New York, 1973.

Ehret, G., Merzenich, M.M.,Complex sound analysis (frequency resolution, filtering and spectral integration) by single units of the inferior colliculus of the cat. Brain Res. 1988 Apr-Jun; 472(2):139-63.

Öjemann, G.A., Models of the brain organization for higher integrative functions derived with electrical stimulation techniques. Hum Neurobiol. 1982; 1(4):243-9.

Olsson, O., Psychoacoustics and Hallucinating Schizophrenics; A Psychobiological Approach to Schizophrenia. Thesis, Lund 2000.

Links, S.K.E., Baldeweg, T., Friston, K.J., Synaptic plasticity and dysconnection in schizophrenia. Biol Psychiatry, 2006 May 15; 59(10):929-39. Freedman R, Adler LE, Gerhardt GA, Waldo M, Baker N, Rose GM, Drebing C, Nagamoto H, Bickford-Wimer P, Franks R., Neurobiological studies of sensory gating in schizophrenia. Schizophr Bull. 1987;13(4):669-78.

Todd, J. M. PT, Schall, U., Karayanidis, F, Yabe, H., Näätänen, R.,Deviant matters: duration, frequency, and intensity deviants reveal different patterns of mismatch negativity reduction in early and late schizophrenia.Biol Psychiatry. 2008 Jan 1;63(1):58-64.

Green MF, Mintz J, Salveson D, Nuechterlein KH, Breitmeyer B, Light GA, Braff DL.,Visual masking as a probe for abnormal gamma range activity in schizophrenia.

Biol Psychiatry. 2003 Jun 15;53(12):1113-9.

Nielzén, S., Geissler, A., Olsson, O., Lanzenberger, R., Tahamtan, N., Gartus, A., Deecke, L., Källstrand, J., Beisteiner, R. CNS-activation with experience of auditory streaming. Unpublished manuscript.

Why Noise Improves Memory in ADHD Children

Sverker Sikström
Lund University Cognitive Science, Lund University

Göran Söderlund
Department of Linguistics, Stockholm University, School of psychology, Southampton University, UK

Please address correspondence to:
Sverker Sikström, Lund University Cognitive Science, Kungshuset Lundagård, s-22222 Lund.
Email: Sverker.sikstrom@lucs.lu.se, phone: 0046-70-3614333

Abstract

Noise is typically conceived as being detrimental for cognitive performance. Contrary to this notion recent studies have found that auditory noise may in some cases improve cognition. Recent data and theories suggest that this beneficial effect of noise depends on several factors including the type of task being performed and noise levels. More importantly, whereas some groups of children increase performance during noise other groups declines. From our point of view these findings can be accounted for in a neurocomputational theory where noise interacts with dopamine, environmental factors, and individual levels of dopamine, where well controlled levels of noise may be beneficial for cognitive performance.

Introduction to noise induced enchantments of cognitive performance

Noise is typically considered to be deleterious for cognitive functioning. Under most circumstances cognitive processing is easily disturbed by noise from the environment and non-task distractors, an effect that has been know for a long time (Broadbent, 1954, 1957, 1958a, 1958b). The effect of distraction is believed to be due to competition for attentional resources between the target stimuli and the distractor i.e., the distractor removes attention from the target task. Repeated research on this topic has demonstrated this finding to hold a across a vide variety of target tasks, distractors and participant populations (Belleville et al., 2003; Boman et al., 2005; Hygge et al., 2003; Rouleau & Belleville, 1996; Shidara & Richmond, 2005). Most experiments since Broadbent's days' have dealt with the negative effects of noise and distraction. However recently, in contrast to the main body of evidence regarding distractors and noise, the opposite has been shown. Two studies were able to demonstrate that under certain circumstances ADHD participants could benefit from auditory, task irrelevant noise presented concurrently with the target task (Abikoff et al., 1996; Gerjets et al., 2002). This finding is particular surprising because persons with attentional problems, for example attention deficit hyperactivity disorder (ADHD) children are known to be more vulnerable to distraction compared to normal control children (Blakeman, 2000; Brodeur & Pond, 2001; Higginbotham & Bartling, 1993). These studies did not, however, provide a satisfactory theoretical account for why noise was beneficial for cognitive performance. Our research has recently extended these findings and suggested a theoretical framework for understanding these apparently contradictory results. We showed that auditory stimulation effect had different effects on the memory performance of children with ADHD and control children (Söderlund et al., 2007). These effects were replicated in two studies for children with sub-clinical attentional problems (Söderlund et al., in progress). In this chapter we review or findings that the noise induced improvements in cognitive performance can be accounted for by a statistical phenomenon that occurs in threshold-based system called stochastic resonance. We suggest that auditory noise can, under certain prescribed circumstances, improve attention and cognitive performance in inattentive children. We review a model and findings that shows a link between noise stimulation and cognitive performance. This is accomplished in the Moderate Brain Arousal (MBA) model (Sikström

& Söderlund, 2007), which suggests a link between attention, dopamine transmission, and external auditory noise (white noise) stimulation.

The Moderate Brain Arousal Mode

Stochastic resonance (SR) is the counterintuitive phenomenon by which weak signals that cannot be detected because they are presented under detection threshold, become detectable when additional random (stochastic) noise is added (Moss et al., 2004). SR may be conceived as that noise adds additional energy to the signal and pushes it above the threshold for detection. However, it should be noted that beneficial effect of SR is found also when the threshold is lower than the signal.

SR, although a paradoxical phenomenon, is well established across a range of settings; it exists in any threshold-based system with noise and signal that requires the passing of a threshold for the registering of a signal. Figure 1 is a representation of this phenomenon.

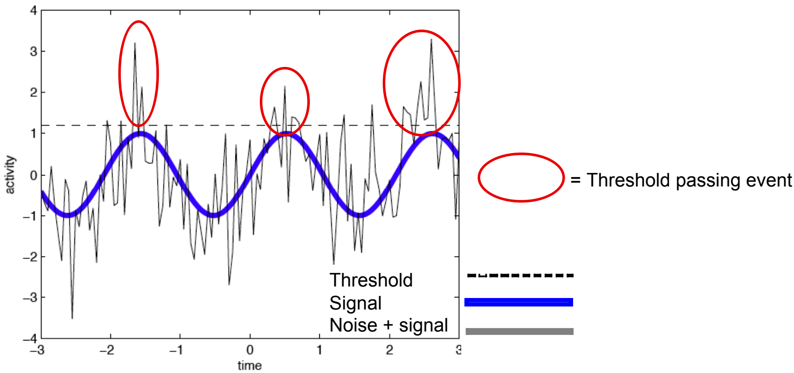

Figure 1: Stochastic resonance where a weak sinusoidal signal goes undetected as it does not bring the neuron over its activation threshold. With added noise, the same signal results in action potentials.

SR has been identified in a number of naturally occurring phenomena and the concept has been used to explain climate changes (Benzi et al., 1982); bistable optical systems (Gammaitoni et al., 1998); mechanoreceptors of the crayfish (Douglass et al., 1993); and the feeding behavior in the paddlefish

(Russell et al., 1999). In particular SR has been found in neural systems and in behavioral data. Threshold phenomena in neural systems are linked to the all-or-none nature of action potentials and they can be modeled by a non-linear activation function, the sigmoid function, that estimates the probability that a neural cell will fire (Servan-Schreiber et al., 1990). This firing probability or gain parameter modifies how responsive a neural cell is to stimulation; the higher gain (less random response) the better performance. In humans SR has been found in the different modalities, including audition (Zeng et al., 2000), vision (Simonotto et al., 1999), and touch (Wells et al., 2005) etc., where moderate noise improves sensory discriminability. In fMRI scans a moderate noise level increased neural cortical activity in visual cortex (Simonotto et al., 1999).

Interestingly, the SR effect is not restricted to sensory processing; SR has been found an enhancing effect in higher cognitive functions as well. Auditory noise improved the speed of arithmetic computations in a normal population (Usher & Feingold, 2000). The amount of noise to induce an SR-effect on higher functions is much higher as compared to the ones used in signal detection experiments. In Usher et al's. (2000) experiment noise levels ranged between 50-90dB and performance, as measured by reaction times, were fastest at 77dB noise level. Moreover, SR can be transferred to other modalities as e.g. auditory noise improves visual detection (Manjarrez et al., 2007) and has a role in the motor system as well (Martinez et al., 2007). SR may also play a role in patients with neuro degenerative disease suggesting that SR may also improve central processing (Yamamoto et al., 2005). Tactile stochastic stimulation provided by vibrating insoles improved balance control in elderly (Priplata et al., 2003), in stroke and diabetes patients (Priplata et al., 2006), and also improved gait i.e. speed, stride length and variability in Parkinson patients' (Novak & Novak, 2006).

Inattention, dopamine and Stochastic Resonance

Noise induced cognitive enhancement is of particular interest in ADHD children that normally are viewed as having severe problem with attention. There are several types of attentional problems, and these problems are also depending on the subtype of ADHD (Nigg, 2005). Paradigms involving attention deficits include; delay aversion, deficit in arousal/activation regulation, and executive function/inhibitory deficits (Castellanos & Tannock, 2002). Delay aversion is the phenomena that characterized by intolerance for waiting and is believed to be related to difficulty in sustaining attention on long and boring tasks (Sonuga-Barke, 2002). Poor regulation of activation or arousal are also connected with inattention (Castellanos & Tannock, 2002) and hyperactivity may be regarded as a form of self-stimulation to achieve a higher arousal level. Executive deficits are predominantly linked to impairments in working memory and effortful attentional control shown in the difficulty to stop an ongoing response and response shift (Casey et al., 1997).

The MBA model suggests that attentional problem adheres from to strong reactions from environmental stimuli that are caused by too low levels of extracellular dopamine. Dopamine signaling comes in two different forms. One form is stimulus independent, more or less continuous and is called tonic firing. This from determines the amount of dopamine in the extra-cellular fluid. The second form is fast and stimulus dependent, and is called phasic dopamine release. The tonic form modulates the phasic form via a pre-synaptic auto feedback mechanism. Autoreceptors in the pre-synaptic cell are activated when the tonic level is too high and suppresses spike-dependent phasic dopamine release. However, when the tonic levels are low the phasic releases increases (Grace, 1995). Too much tonic firing inhibits phasic release and is, according the MBA model, associated with cognitive rigidity. Low tonic levels, in contrast, cause neuronal instability and boosted phasic responses (Grace et al., 2007). Excessive phasic transmission could cause instability in the neuronal network activation and is related to symptoms of failure to sustain attention, distractibility and excessive flexibility that are common in ADHD. It is known that ADHD has low tonic dopamine levels (Volkow et al., 2002) and from the MBA perspective this leads to an abundance of phasic dopamine release and behavioral problems. In this context we prefer to view ADHD not as a discrete category, rather we believe that children could be more or less more likely to have the symptoms that are typical of ADHD and it should be viewed as a continuous dimension. From this view ADHD like symptoms are spread in the in the populations and can explain inattention and hyperactivity seen in normal populations as well. A major insight gained from the MBA model is that individual differences in the level of background noise within the neural system (linked to differences in dopamine signaling) will be reflected in different effects of environmental noise on performance.

Simulation of dopamine in neural cells shows that a neural system with low dopamine levels requires more noise for an optimal performance. This modeling has been contacted in the MBA model where dopamine is manipulated by the gain parameter. This modeling shows that children with low levels of dopamine (ADHD and inattentive) require more noise than attentive children to perform well in cognitive tasks. Attentive children are believed to have enough internal noise for performing well. Therefore, neural systems with low levels of noise, as in inattention, require more external noise for the facilitating effect of SR to be observed. Accordingly, systems with high internal noise levels require less external noise. In this sense the individual levels of neural noise, and the individual SR curve, influence the external noise and performance differently. The effect of noise on performance follows an inverted U-shaped curve. A moderate noise is beneficial for performance whereas too little and too much noise diminish performance. Levels of noise that enhance performance of children with low internal noise attenuate performance for children with higher levels of internal noise. The MBA model takes as an input an external noise and a signal that in turn activates internal neural noise and signal. Through the SR phenomenon these provide an output measured by cognitive performance. Thus, this provides a straightforward prediction of noise-induced improvement in cognitive performance in ADHD and inattentive children.

To conclude, the MBA model predicts that the dopamine system modulates the SR phenomenon leading to that cognitive performance in ADHD and inattentive children benefits from noisy environments. The stochastic resonance curve is right shifted in ADHD due to lower dopamine. The MBA model predicts that for a given cognitive task ADHD children and inattentive children require more external noise or stimulation, compared to control children, in order to reach optimal (i.e. moderate) brain arousal level. This prediction is tested in three studies that are reviewed below.

Experimental support of the MBA model The affirmed predictions of the MBA model have been experimentally tested in three studies consisting of an episodic memory task where participants are learning word pairs. The main manipulations were auditory noise and grouping of children based on ADHD and other behavioral testing. Participants are presented with verbal commands, simple verb – noun sentences such as “roll the ball” or “break the match” (Nilsson, 2000). At the subsequent memory test, participants are instructed to remember as many of the verbal commands presented as possible. Results from the studies are summarized in figures 2 to 4 below. For a more extensive description of study 1 see Söderlund et al. (2007), study 2 and 3 see Söderlund, Sikström and Loftesnes (in preparation).

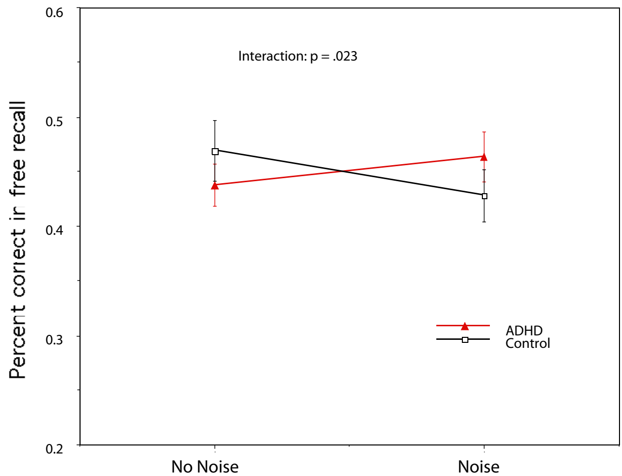

Figure 2. Study 1; Percentage correct recall as a function of noise and group (ADHD vs. Control)

In study 1 (Söderlund et al. 2007), ADHD and normal children participated in a word pair learning task followed by a free recall task, which as conducted either during noise exposure or a silent control condition. The results showed an interaction between noise and group when medicated children where excluded while medication could be a possible confound. ($F(1,33)= 5.73$, $p= .023$, $eta^2= .15$) (see Figure 2). When the medicated group was included, to see if noise effect was present in this group too, in the assessment the interaction between noise and group became stronger ($F(1,40) = 8.41$, $p = 0.006$, $eta^2= .17$).

Study 2 (Söderlund, Sikström and Loftesnes, in preparation) comprised of a normal population of school children where children were divided into groups depending on cognitive performance. Cognitive performance was measured by teacher's judgment of general scholastic skills in three levels: average, above and below average. While the below group only consistedof four participants the below and average groups were merged together Figure 3A shows that the interaction between noise and group is significant ($F(1,30) = 5.92$, $p = 0.021$, $eta^2= .14$). The significant difference between groups in the no noise condition ($t(30)= 3.67$, $p= .001$) disappears in the noise condition (Figure 3A).

Study 3 (Söderlund, Sikström & Loftesnes, in preparation) were an extension and replication of study 2, which also consisted of a normal population of school children. The children were grouped according to (1) teachers' judgments of general school performance, (2) teacher judgments of inattention/hyperactivity, and (3) the score on a Raven test. The results are presented in figures 3B, 4A, and 4B (below), note that group sizes differ between the figures

In Study 3, there was a significant interaction effect between noise and below/above groups, however, there was no interaction effect involving the middle group (Figure 3B). Note that the memory performance level was significantly lower for the below group as compared to the average and above groups ($F(2,48) = 8.51$, $p = .001$).

In Study 3, there was a significant interaction effect between noise and below/above groups, however, there was no interaction effect involving the middle group (Figure 3B). Note that the memory performance level was significantly lower for the below group as compared to the average and above groups ($F(2,48) = 8.51$, $p = .001$).

Figure 3A

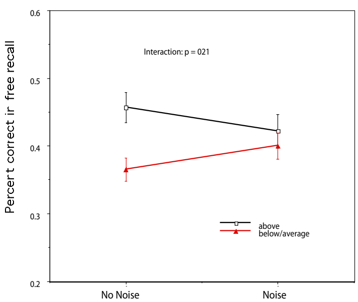

Figure 3B

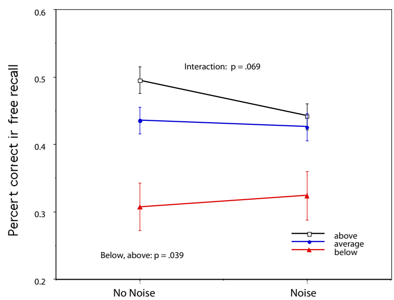

Figure 3A. Recall performance as a function of noise and school performance in two groups (teachers judgments: above N= 12, below/average N= 20).

Figure 3B. Study 3: Recall performance as a function of noise and school performance (teachers judgments in three groups: above N= 22; average N= 22; below N= 7).

In Study 3, the interaction between noise and Raven score was significant (F(2,48)= 3.35, p= .044, eta2=.12) (Figure 4B). Note that the difference in memory performance between below and high performing groups disappeared with noise exposure when t-tested separately. Figure 4A shows the lowest p-value in the interaction between attention and noise (F(2,48)= 4.99, p= .011, eta2=.17). Inattentive children did benefit most from noise and there was no main effect on performance of group, all groups performed at the same level (F(2,48) = 1.28, p = .288).

Conclusions

Traditionally, noise has been conceived as being detrimental for cognitive performance. Recent results from our laboratory shows that this picture has to be revised. Several independent datasets are now showing that noise may actually be beneficial for cognition. However, this beneficial effect only occurs in well defined circumstances. First of all the volume of the noise has to be well tuned for the task. Our data (see also Usher, 2000) shows beneficial effect during noise levels within 70-80 decibel, where lower levels show weaker or absent effects, and higher volumes are detrimental for performance. The aforementioned noise levels apply to cognitive testing and are much larger than the noise levels showing benefits in perceptual auditive tests, where most of stochastic resonance studies have been conducted. More importantly, our studies shows that the benefit of noise differ depending on the groups of participants, where some groups show benefits in cognitive performance by noise, whereas for other groups a decline in performance is found for the same noise levels. Groups that show benefits in performance are ADHD children and children with low cognitive skills, whereas normal controls and particularly high achieving children show decline in performance. The decline in performance for some of the groups should not be interpreted as that noise always is bad for these groups. In contrast the MBA framework suggests that these participants may benefit of noise at other noise levels, or in other task. This framework further suggests that moderate amount of noise may increase the neural activity to optimal levels, and function as a substitute for insufficient dopamine levels. Further studies from our group will focus on directly measure how noise influence dopamine levels and the neural activity. This line of research may potential lead to possibilities of tuning our neural systems to optimal levels. In the future, this environmental therapy may be an alternative to classical pharmacological therapies.

References

Abikoff, H., Courtney, M. E., Szeibel, P. J., & Koplewicz, H. S. (1996). The effects of auditory stimulation on the arithmetic performance of children with ADHD and nondisabled children. *Journal of Learning Disabilities, 29*(3), 238-246.

Belleville, S., Rouleau, N., Van der Linden, M., & Collette, F. (2003). Effect of manipulation and irrelevant noise on working memory capacity of patients with Alzheimer's dementia. *Neuropsychology, 17*(1), 69-81.

Benzi, R., Parisi, G., Sutera, S., & Vulpiani, A. (1982). Stochastic resonance in climatic change. *Tellus, 34*, 10-16.

Blakeman, R. S. (2000). ADHD and distractibility: The role of distractor appeal. *Dissertation Abstracts International: Section B: The Sciences & Engineering, 61*(1-B), 517.

Boman, E., Enmarker, I., & Hygge, S. (2005). Strength of noise effects on memory as a function of noise source and age. *Noise Health, 7*(27), 11-26.

Broadbent, D. E. (1954). Some effects of noise on visual performance. *Quarterly Journal of Experimental Psychology, 6*, 1-5.

Broadbent, D. E. (1957). Effects of noises of high and low frequency on behaviour. *Ergonomics, 1*, 21-29.

Broadbent, D. E. (1958a). Effect of noise on an "intellectual" task. *Journal of the Acoustical Society of America, 30*, 824-827.

Broadbent, D. E. (1958b). The effects of noise on behaviour. In. Elmsford, NY, US: Pergamon Press, Inc.

Brodeur, D. A., & Pond, M. (2001). The development of selective attention in children with attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology, 29*(3), 229-239.

Douglass, J. K., Wilkens, L., Pantazelou, E., & Moss, F. (1993). Noise enhancement of information transfer in crayfish mechanoreceptors by stochastic resonance. *Nature, 365*(6444), 337-340.

Gammaitoni, L., Hänggi, P., Jung, P., & Marchesoni, F. (1998). Stochastic resonance. *Reviews of Modern Physics, 70*(1), 223-287.

Gerjets, P., Graw, T., Heise, E., Westermann, R., & Rothenberger, A. (2002). Deficits of action control and specific goal intentions in hyperkinetic disorder. II: Empirical results/Handlungskontrolldefizite und störungsspezifische Zielintentionen bei der Hyperkinetischen Störung: II: Empirische Befunde. *Zeitschrift für Klinische Psychologie und Psychotherapie: Forschung und Praxis, 31*(2), 99-109.

Higginbotham, P., & Bartling, C. (1993). The effects of sensory distractions on short-term recall of children with attention deficit-hyperactivity disorder versus normally achieving children. *Bulletin of the Psychonomic Society, 31*(6), 507-510.

Hygge, S., Boman, E., & Enmarker, I. (2003). The effects of road traffic noise and meaningful irrelevant speech on different memory systems. *Scandinavian Journal Psychology, 44*(1), 13-21.

Manjarrez, E., Mendez, I., Martinez, L., Flores, A., & Mirasso, C. R. (2007). Effects of auditory noise on the psychophysical detection of visual signals: cross-modal stochastic resonance. *Neurosci Lett, 415*(3), 231-236.

Martinez, L., Perez, T., Mirasso, C. R., & Manjarrez, E. (2007). Stochastic resonance in the motor system: effects of noise on the monosynaptic reflex pathway of the cat spinal cord. *J Neurophysiol, 97*(6), 4007-4016.

Moss, F., Ward, L. M., & Sannita, W. G. (2004). Stochastic resonance and sensory information processing: a tutorial and review of application. *Clinical Neurophysiology, 115*(2), 267-281.

Novak, P., & Novak, V. (2006). Effect of step-synchronized vibration stimulation of soles on gait in Parkinson's disease: a pilot study. *J Neuroeng Rehabil, 3*, 9.

Priplata, A. A., Niemi, J. B., Harry, J. D., Lipsitz, L. A., & Collins, J. J. (2003). Vibrating insoles and balance control in elderly people. *Lancet, 362*(9390), 1123-1124.

Priplata, A. A., Patritti, B. L., Niemi, J. B., Hughes, R., Gravelle, D. C., Lipsitz, L. A., et al. (2006). Noise-enhanced balance control in patients with diabetes and patients with stroke. *Ann Neurol, 59*(1), 4-12.

Rouleau, N., & Belleville, S. (1996). Irrelevant speech effect in aging: an assessment of inhibitory processes in working memory. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 51*(6), P356-363.

Russell, D. F., Wilkens, L. A., & Moss, F. (1999). Use of behavioural stochastic resonance by paddle fish for feeding. *Nature, 402*(6759), 291-294.

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.

Shidara, M., & Richmond, B. J. (2005). Effect of visual noise on pattern recognition. *Exp Brain Res, 163*(2), 239-241.

Simonotto, E., Spano, F., Riani, M., Ferrari, A., Levero, F., Pilot, A., et al. (1999). fMRI studies of visual cortical activity during noise stimulation. *Neurocomputing:*

An International Journal. Special double volume: Computational neuroscience: Trends in research 1999, 26-27, 511-516.

Söderlund, G. B. W., Sikström, S., & Loftesnes, J. M. (in progress). Noise is Not a Nuisance: Noise Improves Cognitive Performance in Low Achieving School Children.

Söderlund, G. B. W., Sikström, S., & Smart, A. (2007). Listen to the noise: Noise is beneficial for cognitive performance in ADHD. *Journal of Child Psychology and Psychiatry, 48*(8), 840-847.

Usher, M., & Feingold, M. (2000). Stochastic resonance in the speed of memory retrieval. *Biological Cybernetics, 83*(6), L11-16.

Wells, C., Ward, L. M., Chua, R., & Timothy Inglis, J. (2005). Touch noise increases vibrotactile sensitivity in old and young. *Psychological Science, 16*(4), 313-320.

Yamamoto, Y., Struzik, Z. R., Soma, R., Ohashi, K., & Kwak, S. (2005). Noisy vestibular stimulation improves autonomic and motor responsiveness in central neurodegenerative disorders. *Ann Neurol, 58*(2), 175-181.

Zeng, F. G., Fu, Q. J., & Morse, R. (2000). Human hearing enhanced by noise. *Brain Research, 869*(1-2), 251-255.

Zentall, S. S., & Zentall, T. R. (1983). Optimal stimulation: A model of disordered activity and performance in normal and deviant children. *Psychological Bulletin, 94*(3), 446-471.

Tinnitus and Hypersensititvity to Sounds

Gerhard Andersson, Prof.

Department of Behavioural Science and Learning, Linköpings University,Swedish Institute for Disability Research.
Department of Clinical Neuroscience, Karolinska Institutet
Email: Gerhard.andersson@liu.se

Introduction

In this text the phenomena of tinnitus and hypersensitivity to sound will be highlighted. Tinnitus is defined as the experience of sound that does not come from an exterior source. One can speak of tinnitus as "sound in silence". It often concerns shrieking, whistling, rushing sounds, but many other sounds may occur (Andersson, 2000). On the other hand, tinnitus does not include meaningful sound. The experience of, for example voices or music does not count as tinnitus. The occurrence of tinnitus is widespread. At least 15% of the adult population have some form of recurring tinnitus, even if a lesser part of these are troubled by it. Epidemiological studies suggest that 2% of the population suffer from severe tinnitus. The problem increases with age and is rare among younger people, but common among the elderly. In certain cases tinnitus can occur in children and the risks of exposure to noise among youngsters should be taken seriously (Olsen Widen and Erlandsson, 2004). It should be added that musicians can often get tinnitus which is related to the exposure to sound their ears suffer in the musician´s profession. The fact remains though that tinnitus increases with progressive age, which mainly depends on increasing hearing impairment among the elderly, and that tinnitus has close proximity to hearing impairment.

Sound sensitivity is a closely related phenomenon, especially with regard to extreme sound sensitivity so called *hyperacusis* (Andersson et al., 2005b). This pertains to sensitivity to everyday sounds, and not therefore only to loud sounds, which is reported by almost half the population. The term hyperacusis means that the patient reacts strongly to the screwing up of a piece of paper, traffic, and a number of sounds that would not usually lead to reactions of pain or distress. A small number go so far as to protect themselves with earplugs, which in some cases can be motivated for loud sounds, but for everyday sounds tends to leads to the patient becoming more sensitive (Formby et al., 2003). The prevalence of hyperacusis is unclear, but a Swedish study found an prevalence of 9% (Andersson et al., 2002). If we look at more serious hyperacusis, where the person protects himself, the prevalence is likely to be sufficiently less, 1 -2% (Baguley and Andersson, 2007)

Can it be measured?

Tinnitus is measured, as is pain, with the help of evaluation on the part of the patient. Tinnitus has certainly objectively been established in the brain with the help of brain scanning techniques, but these have, as yet, no practical clinical use (Andersson et al., 2005a). It is of interest that tinnitus appears to engage those parts of the brain that "interpret sound", that is to say secondary areas in the auditory cortex. Even activation in the areas that steer attention (Andersson et al., 2006) and emotion (Lockwood et al., 1998) has been observed. Although the sound of tinnitus itself cannot be measured, it is important to measure hearing levels and to make other possible tests to investigate hearing pathology and problems that may be related to, for example, the jaw. With the help of an audiometer one can partly recreate tinnitus and ask the patient to evaluate the level. One can also ask the patient to report when tinnitus can no longer be heard if it is masked by an external sound (static). These methods have no obvious clinical relevance, but can be experienced as important by the patient as the symptoms are being taken seriously.

Sound sensitivity and hyperacusis are also measured mainly by self-report scales and patient interviews. Distress thresholds can be measured with an audiometer, but in certain cases this is impossible or of no diagnostic value, as it is unreliable and dependent on instructions. In other words, the patient can "cope" in the test situation, but be tormented by the same level of sound in everyday life. Sound sensitivity occurs frequently among those afflicted with tinnitus and hearing impairments. In this instance it should be noted that it can imply so called *recruitment*, which is a term to describe a greatly increased level of discomfort with loud sounds, but which does not apply to everyday sounds. Recruitment means that sound level increase is not linear. This is something that modern hearing aids are often capable of handling. Hyperacusis is not the same thing, but recruitment and hyperacusis can be present together, especially if the term hyperacusis is not reserved for people without hearing impairment.

Problems connected to tinnitus and sound sensitivity

If we start with tinnitus we can list *the complaint categories* that are related to tinnitus trouble. These include sleeping problems, depression and anxiety, hearing problems and concentration problems that the patient relates to tinnitus (Andersson et al., 2005a). With severe tinnitus, simultaneous depression and anxiety are not unusual (Zöger et al., 2001). The handicap can apply to work and participation in life in general. Some severely affected tinnitus patients cannot accept that they have tinnitus and avoid situations. Tinnitus can be stressful for some, but stress alone is not thought to cause tinnitus, it rather exacerbates the discomfort and becomes a consequence of tinnitus. By far the most common problem that tinnitus patients describe is that tinnitus never disappears and that they "miss silence" (Andersson and Edvinsson, 2008). Discomfort can vary. For some, sleep is the most troublesome while for others it might be concentration.

The handicap caused by hyperacusis is similar to problems suffered by patients with chronic pain. It often concerns difficulty in remaining in certain environments. Partaking in activities may also prove difficult. For musicians hyperacusis can, for example, mean that they cannot continue with their work.

Which groups have the greatest problems?

In glaring contrast to what is reported in the newspapers, it is older people who have the greatest problem with tinnitus (Davis and El Rafiae, 2000). However, they seldom seek help for their tinnitus trouble and the typical tinnitus patient in the clinic is likely to be in their fifties. Although it happens that young people can be afflicted with acute tinnitus, but they seldom develop long term symptoms, even if these can occur. Severe tinnitus in children is rare. There is no clear gender difference, but men and women differ in their discomfort. There are several factors which increase the risk of developing severe tinnitus. The degree of hearing impairment, dejection and anxiety, and according to one theory, the degree to which tinnitus is associated with something negative are factors that can predetermine the development of tinnitus trouble (Andersson and Westin, 2008).Concerning hyperacusis there is still little support from research, but in clinic we often see such professional groups as teachers and musicians (Anari et al., 1999). We should remember though that not everybody with hyperacusis can be found within the world of audiology (Andersson et al., 2005). With hyperacusis, migraine attacks for example, are common.

What forms of treatment are there and how successful are they?

There are many forms of treatment that have been tried on tinnitus. One category attempts to silence tinnitus. In principle there is nothing to support that this works, with the exception of patients with an obvious ear pathology which can be treated surgically (e.g. otosclerosis). On the other hand there is more hope for the kind of treatment that concentrates on alleviating distress. *Cognitive Behavioural Therapy* (CBT) can be found among these, which is the method that has the strongest support in research (Martinez Devesa et al., 2007). CBT includes working with relaxation, thoughts, concentration, and where relevant, sleep, and noise sensitivity. A self-help book based on CBT principles is available in Swedish (Kaldo and Andersson, 2004), and has been tried with good results in a controlled study (Kaldo et al., 2007). A method called *Tinnitus Retraining Therapy* (TRT) has some support (Jastreboff and Hazell 2004). There exist a number of other experimental methods and several complimentary medical treatments such as acu-puncture. Support for these is virtually non-existent or of doubtful quality. Severely afflicted patients with diagnosed depression can be helped by antidepressant drugs. But antidepressants should not be prescribed for most tinnitus patients according to a Cochrane review (Baldo et al., 2006). The treatment of hyperacusis is often good, but there are unfortunately no controlled studies to support this statement. Hyperacusis treatment requires a gradual approach (exposure) to sound, without the patient protecting himself too much. Sound stimulators that produce static can help, but for the most severe cases one should consider a referral to a psychologist with a focus on CBT. (Baguley and Andersson, 2007).

Conclusions

Tinnitus and sound sensitivity are common phenomena which we only partly understand. Tinnitus research is an active area and several different methods of treatment have been tried. With regard to extreme sensitivity to sound there is so far very little research. Modern psychological research studies cognitive mechanisms, but also strategies to better enable the acceptance of that tinnitus cannot be cured. Certain forms of tinnitus may, in the future, be curable, but at the moment no safe and guaranteed effective method exists that can silence tinnitus. However, there is much that can be done to relieve discomfort, and among these methods CBT has the strongest support in research.

(Translation: Janet Kinnibrugh)

References

ANARI, M., AXELSSON, A., ELIASSON, A. & MAGNUSSON, L. (1999) Hypersensitivity to sound. Questionnaire data, audiometry and classification. *Scandinavian Audiology,* 28**,** 219-230.

ANDERSSON, G. (2000) *Tinnitus: orsaker, teorier och behandlingsmöjligheter,* Lund, Studentlitteratur.

ANDERSSON, G., BAGULEY, D. M., MCKENNA, L. & MCFERRAN, D. J. (2005a) *Tinnitus: A multidisciplinary approach,* London, Whurr.

ANDERSSON, G. & EDVINSSON, E. (2008) Mixed feelings about living with tinnitus: a qualitative study. *Audiological Medicine,* 6, 48-54.

ANDERSSON, G., JÜRIS, L., KALDO, V., BAGULEY, D. M., LARSEN, H. C. & EKSELIUS, L. (2005b) Hyperacusi – ett outforskat område. Kognitiv beteendeterapi kan lindra besvären vid ljudöverkänslighet, ett tillstånd med många frågetecken *Läkartidningen,* 44, 3210-3212.

ANDERSSON, G., JÜRIS, L., TRAUNG, L., FREDRIKSON, M. & FURMARK, T. (2006) Consequences of suppressing thoughts about tinnitus and the effects of cognitive distraction on brain activity in tinnitus patients. *Audiology & Neurootology,* 11, 301-309.

ANDERSSON, G., LINDVALL, N., HURSTI, T. & CARLBRING, P. (2002) Hypersensitivity to sound (hyperacusis). A prevalence study conducted via the Internet and post. *International Journal of Audiology,* 41, 545-554.

ANDERSSON, G. & WESTIN, V. (2008) Understanding tinnitus distress: Introducing the concepts of moderators and mediators *International Journal of Audiology*, 47(Suppl. 2), 178-183.

BAGULEY, D. M. & ANDERSSON, G. (2007) *Hyperacusis: Mechanisms, diagnosis, and therapies,* San Diego, Plural Publishing Inc.

BALDO, P., DOREE, C., LAZZARINI, R., MOLIN, P. & MCFERRAN, D. J. (2006) Antidepressants for patients with tinnitus. *Cochrane Database of Systematic Reviews,* CD003853.

DAVIS, A. & EL RAFAIE, A. (2000) Epidemiology of tinnitus. IN TYLER, R. S. (Ed.) *Tinnitus handbook.* San Diego, Singular. Thomson Learning.

FORMBY, C., SHERLOCK, L. P. & GOLD, S. L. (2003) Adaptive plasticity of loudness induced by chronic attenuation and enhancement of the acoustic background. *Journal of the Acoustical Society of America,* 114, 55-58.

JASTREBOFF, P. J. & HAZELL, J. (2004) *Tinnitus retraining therapy: Implementing* *the neurophysiological model,* Cambridge, Cambridge University Press.

KALDO, V. & ANDERSSON, G. (2004) *Kognitiv beteendeterapi vid tinnitus,* Lund, Studentlitteratur.

KALDO, V., RENN, S., RAHNERT, M., LARSEN, H.-C. & ANDERSSON, G. (2007) Use of a self-help book with weekly therapist contact to reduce tinnitus distress: a randomized controlled trial. *Journal of Psychosomatic Research,* 63, 195-202.

LOCKWOOD, A. H., SALVI, R. J., COAD, M. L., TOWSLEY, M. L., WACK, D. S. & MURPHY, B. W. (1998) The functional neuroanatomy of tinnitus. Evidence for limbic system links and neural plasticity. *Neurology,* 50, 114-120.

MARTINEZ DEVESA, P., WADDELL, A., PERERA, R. & THEODOULOU, M. (2007) Cognitive behavioural therapy for tinnitus. *Cochrane database of systematic reviews (Online)*, CD005233.

OLSEN WIDÉN, S. & ERLANDSSON, S. (2004) Self-reported tinnitus and noise sensitivity among adolescents in Sweden. *Noise and Health,* 7, 29-40.

ZÖGER, S., HOLGERS, K.-M. & SVEDLUND, J. (2001) Psychiatric disorders in tinnitus patients without severe hearing impairment: 24 month follow-up of patients at an audiological clinic. *Audiology,* 40, 133-140.

”It Sounds like a Buzzing in my Head”

– children’s perspective of the sound environment in pre-schools

Kerstin Persson Waye, PhD, Assoc professor.

Occupational and Environmental Medicine, Sahlgrenska Academy
Gothenburg University.
Email: kerstin.persson-waye@amm.gu.se

1 INTRODUCTION

Previous investigations indicate that noise may be a serious occupational and public health problem in preparatory schools [1,2]. Typical A-weighted sound pressure levels (LpAeq 8h) are in the range of 75-80 dB in Sweden. Data from our own measurements in pre-schools show similar tendencies, with personnel on average being exposed to 78 dB LpAeq 95% CI (77.3-78.7) when being indoors. Children are generally exposed to higher levels and our data show that they on average are exposed to 85dB LpAeq 95%CI (83.7-86.3) when being indoors. The individual exposure dose is affected by the own voice and parallel studies [3,4] have resulted in estimations of the contribution of voice during different conditions. For example if the wearer of the dosimeter is speaking during 50% of the time in a background level of 70 dB LpAeq the contribution can be estimated to 5 dB, and if speaking during 20% of the time the estimated contribution is 3 dB. How this applies to the field situation remains to be analyzed.

The main sources for the sounds are children activities in the rooms. The level and the sound characteristics are influenced by the room acoustics, the total number of children, the number of children per room, but also other factors such as the pedagogic methods applied, the awareness of the noise problem, the occurrence of other noise sources such as traffic and ventilation systems can be expected to play a role. Official statistics from the work environment show that fifty percent of the female pre-school teachers report that they are exposed to sound levels that make it impossible to speak with a normal voice during at least 25% of their working day [5]. Reported problems among the personnel are “tired ears”, general tiredness, lack of energy, stress and voice problems. [2, 6, 7]. The adverse health effects of these rather high sound pressure levels and long exposure times per day for preschool children are less well known. It has been suggested that children may be at particular risk of developing noise induced hearing impairment [8,9], due to their behaviour at play and possibly to increased age-related vulnerability [9], but precise knowledge is lacking. As children need a better signal to noise ratio to understand speech as compared to normal hearing adults, the noisy environments in pre-schools could lead to a reduced or delayed understanding of speech and later impaired reading and writing abilities [10, 11]. Children with another mother tongue than Swedish and children with hearing impairment are especially affected. In order to make themselves heard in the noisy environment, pre-school children need to raise their voices or in fact scream and there is a risk for acute and chronic voice disorders [12, 13]. Apart from these effects it can not be excluded that noise also for children lead to a general tiredness, reduced wellbeing and stress related symptoms.

It could be assumed that children who voluntary and gladly produce sounds when they play also would be less disturbed or distressed by these. While this may be true for shorter periods of the day, we do not know how they feel when spending 6-10 hours in a noisy environment.

In order to increase the knowledge of how the sound environment at pre-schools affects the health of children and personnel a three-year research project has been initiated at Occupational and Environmental Medicine. The project is financed by the Swedish council for working life and Social research (FAS) and the Swedish research council for Environment, Agricultural Sciences and Spatial planning (FORMAS). A further aim is to evaluate the results of an intervention program aimed to improve the acoustic conditions at pre-schools and finally to see if the improved acoustic conditions have a positive effect on health.

The study sites are all in the city of Mölndal - a municipality of about 59000 inhabitants in the south west of Sweden. The study population comprises seven randomly selected pre-schools. They were part of a larger renovation program in the city of Mölndal with special emphasis to improve the acoustic conditions in order to reduce the noise levels generated by the activities inside the pre-schools. The study population also comprises three pre-schools where no renovation had been undertaken (controls).

The renovation program include putting up ceiling panels (absorbents class A), and also in some cases addition of absorbents to one wall in the children's play room, change of flooring to vinyl flooring with acoustic properties. The chairs are fitted with chair pads. In all pre-schools, including the controls, the table surface is made of an acoustically soft material (type vinyl Tapiflex).

The selected pre-schools are studied in the autumn one month before the renovation and in the spring at least three months after the renovations. Measurements of noise levels are done during a week using sound level meters (B&K 2260) with the microphone hanging from the ceiling in the rooms, individual dosimeters (SPARK 705+) worn every day by two children and two personnel. Room acoustic measures are done in empty rooms before and after the renovation. Subjective data are collected using questionnaires distributed to the personnel, the parents while the children are interviewed. Voice-data are recorded at four specific intervals during the day, as well as during activities during the day for one child and one personnel.

Before the study, a number of challenges were identified, the major being that methods to study the effects of noise on pre-school aged children were lacking. We did not know how preschool-aged children recognize, communicate, perceive and are affected by the sounds at their preparatory school. This knowledge was necessary in order to develop a questionnaire assessing possible adverse effects on children. The process carried out to develop the interview questionnaire to be used for children aged 4-6 years will be summarised in the following. For further information see [14].

2 Children´s Perspectives of Sound Environment in Pre-schools

2.1 A qualitative approach

Constructivist grounded theory was used as the qualitative approach, taking the perspective that individuals create social realities through their interpretation as well as through individual and collective actions [15].

2.2 Sampling procedure and study-sample

The preschools were strategically selected, to capture a variation of soundscapes environments and pedagogic principles. Prior to each interview the children's parents were informed about the study and gave their written consent. Also the children were asked whether they would like to participate or not. All children in the five selected preschools, 4-6 years old and present the day the interviews took place was interviewed. This formed a sample of 36 young children. The sampling and data-collection proceeded parallel with analysis, in line with grounded theory methodology, until theoretical saturation was reached.

2.3 Focus-group interviews

Qualitative focus group interviews were used in order to generate a depth of understanding into the young children's shared perceptions and experiences of the preschool sound environment [16, 17]. Their perceptions of positive and negative sounds were explored as well as their perceptions and management of consequences. Eleven focus group interviews with 1-3 participants in each group were completed.

2.4 Qualitative analysis

The analysis of data was in line with constructivist grounded theory approach [14], with initial systematic description and secondly conceptualising theory development. Theoretical notes and theoretical discussion within the research group was used to deepen the analysis. The interviews were coded in order to describe categories and their relations.

3 RESULTS

3.1 Qualitative description of young children's perception of the sound environments at pre schools

The result describes how young children relate their experience of sounds to which consequences the sound had for themselves, the type of sound, their understanding of its source, their bodily experience of the sound and the communicating opportunities the sound may have for them.

I general four categories of sounds could be deduced from the data: Threatening sounds, High frequency sounds, Background sounds and Communicating sounds.

Threatening sounds

Threatening sounds were sounds like: screams, cry and angry voices. These sounds were experienced as negative, threatening and discomforting. The interviewed young children did often relate this noise to a certain child, which often screamed and thereafter became angry, violent or very sad and upset. The interviewed children described their discomfort in these situations.

High-frequency sounds

Children also described high discomfort when there were high-frequency noises at the preschool. Squeaking, creaking and scratching noise was described as unexpected and as a physical experience. For example noise from squeaking and creaking bicycles, table wares, plates, doors or swings.

Background sounds

Background sounds from e.g. a fan, radiators, computers were often non-reflected, unknown sounds, not easy to communicate. Many children noted these sounds but some did not notice them at all, although there might be high at rather high levels. Children also showed their uncertainty and lack of knowledge about the source of the background noise, making it difficult to communicate and reflect upon it.

Communicating sounds

Some expressed sounds were interpreted as communicating and learned noise. These sounds could be sounds from animals, e.g. how a dog sounds.

Or, family noises such as “my mum is snoring”.

Strategies for discomforting sounds

The strategies mentioned by the children when hearing discomforting sounds were holding their ears, hiding, running away, running out to the play-ground or go to the teacher.

Described bodily experience of sounds

The young children described “how they felt” when they were exposed to disliked sounds. The descriptions were often physical and emotional. They could experience a “pain in their ears”, that they felt it, in their stomach, that their heart was beating very fast, that it hurt in their head or spin in their head or just that they felt bad and felt discomfort. They handled this by avoiding strategies, e.g. withdrawal and “holding their ears”, hiding, running away or running out to the play-ground.

4 CONCLUDING COMMENTS

Personnel and to an even higher degree children at pre-schools are exposed to high sound levels during time spent indoors. In order to better understand how children perceive their sound environment focus group interviews were carried out. The qualitative methods used gave us insights beyond what could have been achieved using the common quantitative measurement techniques.

The children’s experience of sounds was related to which consequences the sound had for them in their immediate being. They described various experience related to the type of sound and also their understanding of its source. Further, their described consequences were typically experienced as physical, i.e. as within their bodily. Their descriptions of sounds they disliked could be formed into different categories of sounds. These sounds were disliked to a high degree and resulted in avoidance strategies among the children. The findings also enabled us to construct a questionnaire that is used in interviews with children.

5 AKNOWLEDGEMENTS

The research group for this part of the project involves Lotta Dellve, PhD, Lena Samuelsson, Special needs educator, Agneta Agge research assistant, Occupational and Environmental Medicine, The Sahlgrenska Academy Gothenburg University.

6 REFERENCES

A. Bertilsson, A-C. Hagaeus, Y. Sandqvist, K. Skagelin, M. Björkman and L. Barregård, " Report from sound level measurements in preschools and schools in the municipalities of Lidköping and Skara 2000-2003," The Community of Lidkoping and Skara and Department of Public Health and Community Medicine, Goteborg (2003). (In Swedish)

U. Landström, B. Nordström, A. Stenudd and L. Åström, "Effects of the number of children on noise levels and of the experience among staff in preschools," Working Life Report nr 6, 1-43. ISSN 1401-2928 (2003). (In Swedish)

Ryherd, S., Persson Waye, K. Kleiner M. Ryherd, E. (2008). Quantifying the Noise Environment: Effects of Wearer's Voice on Body-mounted Noise Dosimeter Measurments. Acoustics'08, Paris, France.

Ryherd, S. R. (2008). Influence of wearer´s voice on noise dosimeter measurements. Chalmers Room Acoustics Group. Gothenburg, Chalmers University of Technology. Master in sound and vibration: 47pp.

The Work Environment 2001, SOS, SM: AM 68 SM 0201. (In Swedish)

B. Fritzell, "Voice problems are related to the profession," Läkartidningen nr 14, 93, 1325-1327 (1996). (In Swedish).

L. Rantala, E. Vilkman and R. Bloigu, "Voice changes during work: subjective complaints and objective measurements for female primary and secondary school teachers," J Voice, **16**(3), 344-55 (2002).

Guidelines for community noise. Edited by Birgitta Berglund , Thomas Lindvall and Dietrich H. Schwela, World Health Organization (WHO) (1999).

W. Passchier-Vermeer, "Noise and health of children," Leiden: TNO report PG/VGZ/2000.042 (2000).

G. W. Evans and S. J. Lepore, "Nonauditory effects of noise on children: a critical review," Child Environ, **10**, 31-51 (1993).

L. Maxwell and G. Evans, "The effects of noise on pre-school children's pre-reading skills," J Environ Psychol, **20**, 91-97 (2000).

A. McAllister, "Acoustic, perceptual and physiological studies of ten-year-old children´s voices," Thesis. Department of Logopedics och Foniatrics, Karolinska University Hospital, Huddinge and Department of Speech, Music and Hearing , KTH, Stockholm, Sweden (1997).

E. Sederholm, "Prevalence of hoarseness in ten-year-old children," Scand J Log Phon, **20**, 165-173 (1995).

Persson Waye, K. Samuelson, L. Agge, A. Dellve, L. (2006). Methods for assessing preschool children's perception and experience of their soundscape. The 2006 Congress and exposition of noise control engineering, Inter-Noise, Honolulu, Hawaii, USA.

K. Charmaz, "Constructing grounded theory – a practical guide through qualitative analysis," SAGE Publications Inc. Thousand Oaks, USA (2006).

R. A. Krueger, "Focus Groups. A Practical Guide for Applied Research," 2ed. Sage Publications. Thousand Oaks, USA (1994).

C. Webb and J. Kevern, "Focus groups as a research method: a critique of some aspects of their use in nursing research," Journal of Advanced Nursing, **33**, 798-805 (2001).

Cognitive Skills and Percieved Effort in Active and Passive

Listening in a Naturalistic Sound Environment

Björn Lyxell[1,2,3], *Erik Borg*[2] *and Inga-Stina Olsson*[2]

[1]Department of Behavioural Sciences, Linköping University, Sweden,
[2]Ahlsén Research Institute, Örebro University, Sweden
[3]The Swedish Institute for Disability Research, Linköping University

INTRODUCTION

Speech understanding is more difficult in situations with background noise than in situations without noise and this is further hampered if the listener is hearing-impaired (Divenyi & Simon, 1999; Hällgren, Larsby, Lyxell & Arlinger, 2001; Schneider, Daneman & Pichora-Fuller, 2002). Understanding speech in noise engages the individual´s cognitive system to a higher extent as a larger portion of the spoken signal is either missing or ambiguous and has to be inferred or disambiguated by means of cognitive operations (Lunner, 2003; Lyxell, Andersson, Olsson & Borg, 2003; Pichcora-Fuller, 2003, Schneider & Pichora-Fuller, 2000). The level of speech understanding may also vary as a function of the type of listening task that is required in the background noise. That is, the performance in listening tasks that requires some form of execution based on the spoken information (i.e., active listening) taxes the individual´s cognitive abilities relatively more compared to listening situations where such requirements are not present (passive listening). The nature of the interfering noise is also important for the degree of interference with speech understanding (e.g. the spectrum and temporal features: Dreschler et al, 2001 and Magnusson, 1995). In order to handle this multivariate situation and to construct useful and reasonably reliable and valid test situations, standard masking noise has typically been composed of, for example speech spectrum noise, babble noise or ICRA-noise (Dreschler et al, 2001) An alternative, but less frequently used, approach is to record and edit naturalistic noise sequences representative of specific classes of enironmental situations (e.g., a specific workplace). In the present study focus is on hearing impaired and normal hearing day-care centre teachers and a typical sound environment at the day-care centre entrance hall was created (cf., Tun & Wigfield, 1999).

The general purpose of the present study is to examine the possible relationship between the individual´s cognitive skills, type of listening situation (active vs passive) in a naturalistic background noise (i.e., the noise specific for their workplace environment) and perceived effort during and after listening. In the study, we will compare the performance of two groups of day-care centre teachers; one with hearing-impairment and a group of matched normal hearing individuals with respect to cognitive skills, perceived effort and listening in naturalistic situations.

In the present study, the listening tasks will be constituted by the "Just-follow-conversation" paradigm (JFC; Hygge, Rönnberg, Arlinger & Larsby, 1992; Hygge, 2003). In this paradigm, the participants listen to a story that is presented against a competing background noise. The background noise is presented at a fixed or individual sound level (65 dB A, most comfortable level, or maximal acceptable level) and the individual´s task is to adjust the sound level of the speaker to a level where it is just possible to follow the content of the story. JFC has proved to be a sensitive method to investigate speech perception in noise for populations of (young and old) hearing-impaired and normal hearing listeners (Borg et al., 1999). Two different JFC-tasks will be used, one with passive and one with active listening. The passive listening condition will follow the standard JFC procedure, where the individual's task is to adjust the sound level of the speaker to the level where they are able to just follow the speaker. This is also the situation in the active listening task but the individuals are, in addition, required at random time intervals during listening, to answer simple questions based on the content of the story. The same story is employed in both tasks and background noise was constituted by noise typically occurring in day-care centres (e.g., children screaming and playing, adults conversing). The hypothesis is that the active listening task will require a more active and effortful processing, i.e. more cognitively demanding listening situation. Thus, being prepared to answer simple questions about the content of a story requires a number of cognitive operations, but primarily that parts of the story are actively held in working memory and that lexical and phonological information stored in long-term memory is accessed relatively fast.

The assessment of the individuals´ cognitive skills will focus on the skills that are central for processing of spoken language, particularly in populations with hearing-loss (Andersson, 2003; Andersson, Lyxell, Rönnberg & Spens, 2001; Lyxell, Andersson, Ohlsson & Borg, 2003; Pichora-Fuller, 2003). Specifically, we will examine three cognitive components; working memory, lexical access speed and phonological processing skills.

A frequent report from hearing-impaired individuals is that listening in general and in noisy environment in particular is effortful and resource demanding. However, few studies have examined how perceived effort relates to cognitive skills and to listening situations with varying cognitive demands. In the present study, perceived effort will be assessed by means of Borgs (1998) CR-10 scale, where level of perceived effort is assessed before, during and after the listening tasks.

METHOD

Participants

The participants in the study were 11 female day-care centre teachers (21 – 65 years) constituting the total number of bilaterally hearing impaired individuals (with one exception) in this profession in the Örebro region (with a total population of 270 000). A group of 11 normal hearing female day-care centre teachers matched for age and work places constituted the control group.

Materials and procedure
Design of sound environment

The acoustic recordings were made in a Swedish day-care centre. The recordings were designed on the basis of observations in the day-care centres and interviews with hearing impaired individuals. Repeated recordings were obtained in the same room, i.e., an entrance hall. The recordings were made with a two channel digital tape recorder, edited off-line (Digidesign session 8) and stored in a computer. Individual recordings were made of different groups of parents and children and combined to create an acoustically active and realistic environment representing a time when several children were leaving the day-care centre. The environments were reproduced in a specially designed test room (Borg et al, 1998, 1999) equipped with twelve loudspeakers. The day care centre environment was presented from eleven loudspeakers and the target sound from loudspeaker 12 (0 degrees azimuth).

Active and passive listening task

In the naturalistic test environment a target speech sound was introduced to the sound environment and the dependent measure was the adjusted sound level of the target sound in dB. This speech material (i.e., the target sound) was a 1-hour recording from Selma Lagerlöf´s book "Nils Holgersson´s wonderful journey". The participants´ task was to adjust the level of the spoken sound to that level where they were able to just follow the conversation (cf, Hygge et al, 1992). Two listening conditions were used in the study: One active and one passive. In the active mode the participants were asked to adjust the sound level in order to be able to just follow the conversation and also to be prepared to answer simple questions on content of the text at random intervals during the test session. In the passive condition the task was to adjust the spoken sound level so that they were able to just follow the conversation.

Perceived effort

The individual´s perceived effort before, during and after listening was assessed by means of G. Borg´s CR-10 scale. During the session this scale was administered halfway through both listening tasks. The participants were asked to indicate on the scale how effortful they experienced the listening task.

Cognitive tests

All cognitive testing was performed individually and administered by a computer test-platform. All instructions regarding the cognitive tasks were presented in written form and complemented with oral instructions.

RESULT

In the first part we will describe the test results and measurements of cognitive capacity and active and passive listening. In the second part we will examine the relationship between the individually selected signal noise ratios in the two listening conditions and the cognitive capacity and how these factors relate to level of perceived effort.

Cognitive capacity

Table I give the descriptive statistics for the cognitive tasks used in the study. As can be seen, the two groups do not differ statistically from each other. The performance levels are further similar to performance levels that have been reported from other studies where the present tasks have been employed (Andersson, 2002; Andersson, Lyxell, Rönnberg & Spens, 2001; Lyxell, Andersson, Arlinger, Bredberg, Harder & Rönnberg, 1996, Lyxell, Andersson, Arlinger, Bredberg & Harder, 1998) and where moderately hearing-impaired, deafened adults and normal hearing individuals have participated in the working memory tasks and the lexical and semantic decision-making tasks. Furthermore, for the hearing-impaired group, the level of hearing loss did not correlate with performance on any cognitive task.

Active and passive listening

The number of errors (i.e., wrong answers to the questions) in the active condition did not differ between the groups and was also low. The results display that there is a highly significant difference between the two groups in both the active and the passive listening condition ($t = 5.13$ and $t = 5.40$, $p < .001$, respectively). It is also interesting to note that the magnitude of the difference is parallel across the two conditions. That is, the two conditions do not interact with each other and the adjusted sound level does not increase as a function of increased cognitive demands for the hearing-impaired group relative to the normal hearing participants. A further inspection of the data reveals that there is a significant difference between the active and the passive listening condition for the normal hearing participants in the study. That is, when the cognitive demands in the listening situation are increasing, the adjusted speech sound level is also increasing. For the group of hearing-impaired individuals, the adjusted signal to noise ratio sound level between the active and the passive listening condition is different, but this difference is not statistically significant ($t = 1.80$, $p > .05$).

An analysis of the results from 0º azimuth at an individual level demonstrates that the pattern of adjusted sound level between the first and the second half of the two listening tasks differs between the two groups. That is, in the active condition most of the hearing impaired individuals increased (i.e., seven individuals increased,two decreased and two remained at the same level) their adjusted sound level (average increase 2.22 in dB), whereas the normal hearing individuals decreased their average adjustment (- .45 dB). A sign test reveals that the change (i.e., increase vs decrease in dB) is significant for the hearing-impaired group ($z = 1.83$, $p < .05$), whereas significance was not reached for the normal hearing group. In the passive condition there is an increase in the adjusted speech sound level for both groups (the hearing-impaired increased with 2.1 dB and the normal hearing group with .81 dB). A sign test yielded significance only for the hearing-impaired group ($z = 2.38$, $p < .05$).

Cognitive performance and active – passive listening

Table 2 gives the correlation coefficients for the two groups in cognitive performance and in the adjusted sound level (signal-to-noise ratio) for loudspeaker 12 in the active and passive listening conditions. The empirical picture for the normal hearing group reveals significant correlation coefficients and the cognitive tasks (with one exception; the semantic decision-making task) and the active listening task. For the passive listening condition, significant correlation coefficients are, with one exception (the rhyme judgement task), absent. The empirical picture for the hearing-impaired participants, on the other hand, demonstrates no pattern of correlation regardless of type of listening situation and cognitive task.

Perceived effort and cognitive performance

The results demonstrate that perceived effort increases, as expected, during and after compared to before the tasks were performed. The hearing-impaired subjects showed consistently higher level of perceived effort than the normal hearing participants. Significance was not reached for the difference between active and passive listening. The pattern of correlations reveal that perceived effort does not correlate in a systematic way with cognitive performance for the hearing-impaired group, whereas we have a systematic pattern of correlations for the normal hearing participants in the active condition for the measurement after the test session.

GENERAL DISCUSSION

The purpose of the present study was to examine the possible relationship between the individual´s cognitive skills, type of listening task in a naturalistic sound environment and perceived effort.

The results can be summarised in five main points: First, the results display no differences in cognitive performance between the two groups. The observation that the groups perform at the same level on the rhyme-judgement task when speed as well as accuracy level are examined is interesting, as this pattern is different in comparison with results reported when participants with a more severe hearing-losses (e.g., a bilateral hearing loss greater than 75 dB for the "best ear") or deafened adults have been studied (Andersson, 2002; Conrad, 1979; Hanson & McCarr, 1988; Lyxell, Rönnberg, & Samuelsson, 1995; Lyxell, Andersson, Arlinger, Bredberg, Harder, & Rönnberg, 1996). Typically, these populations show signs of a deteriorating phonological processing skill. The results from the present sample, with a relatively moderate hearing-loss, may suggest that there is a "breaking-point" in terms of hearing loss where this deterioration starts to operate (c.f., Lyxell & Holmberg, 2001) and that this "breaking-point" is not reached with the level of hearing-loss in the present sample.

Second, the difference in the adjusted sound level between the two groups follows the expectations: The hearing-impaired group adjust the spoken voice to a significantly higher level than the normal hearing participants in both the active and the passive listening condition. For the active – passive manipulation of the listening situations, the pattern of the adjusted sound level for the normal hearing individuals follows again the expectation. That is, a significantly higher adjusted sound level for the active condition compared to the passive is observed. The hearing-impaired participants deviate from this pattern, as their adjusted sound level is higher for the active condition than for the passive, but the difference between the two conditions does not reach statistical significance.

Third, the groups differ in how they adjust the speech sound level between the two measurement occasions. The hearing impaired increased, rather than decreased, the sound level, between occasion one and two, whereas such a pattern was not present in the normal hearing group. This outcome may reflect the fact that listening is more effortfull for the hearing-impaired over time compared to the normal hearing individuals and one way of compensating for this state of affairs is to increase the signal to noise ratio level.

Fourth, the groups differ in how their cognitive skills relate to adjusted sound level in the active versus the passive listening condition. Cognitive skills are correlated to adjusted sound level in the active condition, but not in the passive condition for the normal hearing individuals. Correlations between adjusted sound level and cognitive skill are absent in the hearing-impaired group for both listening conditions. Thus, the outcome for the normal hearing group may imply that the active listening condition is more demanding from a cognitive point of view, whereas the absence in the hearing-impaired group may reflect that the distinction between active and passive listening is not a fruitful one for this population. This will be discussed in some detail below.

Fifth, the two groups differ in perceived effort during and after the listening tasks, but the perceived effort is only reflected in terms of significant correlation coefficients in the normal hearing group for the active listening condition after the test. Hence, perceived effort is related to cognitive capacity for the normal hearing individuals when the listening situation demands a higher extent of cognitive processing. This relation is absent for the hearing-impaired.

The results from the present study for the normal hearing participants displays the expected pattern. That is, an increase in the cognitive demands in the listening situation (i.e., active compared to passive listening) is correlated with cognitive skills and perceived effort, whereas this pattern is not displayed in the hearing-impaired group. There are at least two possible explanations for this state of affairs. First, there is a difference in recruitment between the two groups, such that only a small increase in the speech sound level in the hearing-impaired group generates an impression of a large increase in the speech sound level. Thus, the consequence is that the physical difference in signal to noise ratio between active and passive listening in the hearing-impaired group is small and does not reach significance. A second explanation is that the response criteria differ between the two groups. The normal mode of listening in normal hearing individuals is in most cases a rather effortless or a low cognitively demanding information-processing task. This state changes when the listening task requires a more active processing of information (e.g., answering questions) and/or when the background noise makes parts of the spoken stimuli ambiguous or when pieces of information are missing. The listening situation for the hearing-impaired individuals is, on the other hand, never an effortless task. Parts of the stimuli will always be missing or ambiguous regardless of listening situation. Thus, the distinction between active and passive listening is not valid for the hearing-impaired individuals.

References

Allén, S. (1970). Frequency dictionary of present-day Swedish. (In Swedish: Nusvensk frekvensordbok.). Stockholm: Almquist& Wiksell.

Andersson, U. (2003). Deterioration of the phonological processing skills in adults with an acquired severe hearing loss. European Journal of Cognitive Psychology.

Andersson, U. & Lyxell, B. (1998). Phonological Deterioration in Adults with an Acquired Severe Hearing Impairment. Scandinavian Audiology, 27 (suppl, 49), 93 - 100.

Andersson, U., Lyxell. B., Rönnberg, J., & Spens, K-E. (2001). Cognitive correlates of visual speech understanding in hearing impaired individuals. Journal of Deaf Studies and Deaf Education.

Baddeley, A., Logie, R., Nimmo-Smith, I. & Brereton, N. (1985). Components of fluent reading. Journal of Memory and Language, 24, 119-131.

Baddeley, A. and Wilson, B. (1985). Phonological coding and short-term memory in patients without speech. Journal of Memory and Language, 24, 490-502.

Borg, G. (1998). Borg´s Perceived Exertion and Pain Scales. Champaign, IL: Human Kinetics Publishers.

Borg E, Rönnberg J, Neovius L. (1999). Monitoring the environment: Sound localization equipment for deaf-blind people. Acta Otolaryngol: 119; 146-149.

Borg E, Wilson M, Samuelsson E. (1998). Towards an ecological audiology: Stereophonic listening chamber and acoustic environmental tests. Scand Audiol; 27: 195-206.

Conrad, R. (1979). The deaf schoolchild. London: Harper & Row.

Dreschler, W.A., Verschuurem H., Ludvigsen, C., & Westermann S. (2001) ICRA noises: artificial noise signals with speech-like spectral and temporal properties for hearing instrument assessment. International Collegium for Rehabilitative Audiology. Audiology 40, 148-157

Divenyi, P. & Simon, H. (1999). Hearing in aging: Issues old and young. Current opinion in otolaryngology and head and neck surgery, 7, 282 – 289.

Hanson, V. and McCarr, N. (1989). Rhyme generation by deaf adults. Journal of Speech and Hearing Research, 32, 2-11.

Hygge, S. (2003). Classroom experiments on the effects of different noise sources and sound levels on long-term recall and recognition in children. Applied Cognitive Psychology, 17, 895 – 914.

Hygge, S., Rönnberg, J., Larsby, B. & Arlinger, S. (1992). Normal-hearing and hearing-impaired subjects' ability to just follow conversation in competing speech, reversed speech, and noise backgrounds. J Speech Hear Res, 35, 208-215.

Hällgren, M., Larsby, B., Lyxell, B. & Arlinger, S. (2001). Evaluation of a cognitive test battery in young and elderly normal-hearing and hearing-impaired subjects. J Am Acad Audiol, 12, 357-370.

Lunner, T. (2003) Cognitive function in relation to hearing aid use. Int J Audiol, 42, S49-S58.

Lyxell, B. & Holmberg, I. (2000). Speechreading and cognitive skills in schoolchildren (11 – 14 years). British Journal Educational Psychology

Lyxell, B., Rönnberg, J., & Samuelsson, S. (1994). Internal Speech Functioning and Speechreading in Deafened and Normal Hearing Adults. Scandinavian Audiology, 23, 179-185.

Lyxell, B., Andersson, J., Andersson, U., Arlinger, S., Bredberg, G., Harder, H. (1998). Phonological representation and speech understanding with cochlear implants in deafened adults. Scandinavian Journal of Psychology, 39, 175-179.

Lyxell, B., Andersson, J., Arlinger, S., Bredberg, G., Harder, H., & Rönnberg, J. (1996). Verbal Information-processing Capabilities and Cochlear Implants: Implications for Preoperative Predictors Of Speech Understanding. Journal of Deaf Studies and Deaf Education, 1, 190-201.

Lyxell, B., Andersson, U., Olsson, I-S & Borg, E. (2003). Working memory capacity and phonological processing in deafened adults andindividuals with a severe hearing-impairment. International Journal of Audiology, 42, suppl.1, 86-89.

Magnusson L. Reliable clinical determination of speech recognition scores using Swedish PB words in speech-weighted noise. Scand Audiol 1995; 24: 217-23.

Pichora-Fuller, M.K. (2003). Processing speed and timing in aging adults: psychoacoustics, speech perception, and comprehension. Int J Audiol, 42, S59-S67.

Scheider, B. & Pichora-Fuller, MK. (2000). Implications of perceptual processing for cognitive aging research. In F. Craik & T. Salthouse (eds) The handbook of aging and cognition (pp. 155-219). Mahwah, NJ; L E A.

Schneider, B., Daneman, M. & Pichora-Fuller, M. K. (2002). Listening in aging adults: From discourse comprehension to psychoacoustics. Canadian Journal of Experimental psychology, 56, 139 – 152.

Shoben, E. (1982). Semantic and lexical decisions. In Puff, C. R. (ed.) Handbook of research methods in human memory and cognition. New York: Academic Press.

Tun, P. A. & Wingfield, A. (1999). One voice too many: Adult age differences in language processing with different types of distracting sounds. J Gerontol, 54B, 317-327.

Table 1

Table 1 gives the Mean performance and the SDs on the cognitive tasks for both groups. For the span tests the means reflect the number correct recalled items in each tasks and for the three other tasks mean reaction-time

Cognitive tasks	**Hearing-impaired**	**Normal hearing**	
Reading span	24.75 (5.19)	22.83 (5.16)	ns
Word-span	56.16 (9.98)	57.91 (8.79)	ns
Semantic decision-making	1.01 (.16)	1.00 (.14)	ns
Lexical decision-making	2.57 (.81)	2.38 (.66)	ns
Rhyme-judgement	1.48 (.27)	1.52 (.37)	ns

Table 2

Table 2 gives the correlation coefficients between performance on the cognitive tasks and the adjusted sound level in the active and passive listening condition for both groups.

	Hearing-impaired		**Normal hearing**	
	Active	Passive	Active	Passive
Reading span	.09	-.17	-.69*	-.03
Word-span	-.42	.18	-.49*	.13
Semantic decision-making	-.43	-.08	.23	-.16
Lexical decision-making	-.19	-.23	-.57*	.21
Rhyme-judgement	-.18	-.13	-.56*	-.75*

* $p < .05$, one-tailed

Sound, Catastrophy and Trauma

Åke Iwar

Introduction

Each individual will have different reactions and behaviour in connection to a traumatic experience, and this includes the sensory impressions. In the shock phase especially, patients can describe sensory phenomena as "unreal and supernatural" as though they had considerable amplification of hearing for example. The experience of silence or the absence of sound can be marked, as in the classical expression "you could hear a pin drop". So-called *dissociation* can arise in the shock phase, where time and place can change so that a minute can be like an hour and vice versa the sound experience may have a lengthy, or split second lapse. In connection with robbery, a patient may have reported no experience at all of glass being broken for example, only the impression of the perpetrators eyes or gun, everything else is missing or very diffuse. When the traumatised person enters into the reaction phase, certain flashbacks of sensory experiences such as an explosion, screeching car tyres etc. can suddenly return and often be very frightening. In the case of a severe bus accident 1988 where many children died and many were injured, terrifying memories of the accident were awakened at the hospital when some children recognised the sound of drink being sucked through a straw, which was a similar sound to the sound in the bus exactly prior to the accident. So-called traumatised sensory experience, such as a sound, can of course be unique, for example a bus skidding round on a motorway. In that context the sound was described as "when you crumple up a Coca Cola tin". Sensory experience/sounds can also cause a conflict of feeling as it can be a common everyday sound, and basically a positive one, but transformed by the trauma to one representing danger, threat and death. Another example of so-called sound trauma is told by a patient who had been robbed *twice*, where the first assailant had "only" pointed his pistol at her temple, but the second had fired his pistol in the air. The patient could now experience her own death; the scene and the sound from the *two* traumas became one in her experience.

It appears to be common that one or several sensory experiences disappear or are amplified with trauma, and create permanent scares paired with severe anxiety. According to my clinical experience those traumas that are partly more sudden, and partly violent, have a deeper and more prolonged effect on the patient. One patient who, when young was exposed to sexual violence, could as an adult be frightened by the sound of a door being opened before she could see who it was.

It is of the utmost importance that the traumatised patients receive psychological help for their crises. An important part of crisis counselling is to create security and to work through emotions. Music can also play a meaningful role both in evoking closeness and fascilitating grief reactions.

All events that threaten our security and existence will cause us huge psychological stress. They will challenge our belief in the world as a good and safe place to inhabit.

When we are hit it happens in the middle of our daily lives when we least expect it. In a flash, life changes and will never be the same again. The more sudden the event, the more our psychological preparedness will be challenged. We must face a chaos that will have enormous immediate consequences, but also consequences in the long term. We want the pain to heal as soon as possible and are forced to see that we are no longer invulnerable**.** We will ask ourselves questions like, "Why does this happen to me or my family?" Then we must cope with our daily lives again with all their uncertainty and worry. We try in every way to make sense of what has happened, to bring meaning to the terrible event. This as an attempt to bring knowledge, understanding and meaning as to why we react as we do, when catastrophe threatens our daily lives.

The Myth of Invulnerability

There is a tendency to hide from painful and difficult things that can befall us. Through the media we can take part in how others are affected by violence, accidents, and catastrophes, but we run the risk of failing to see that we ourselves are exposed to the same dangers. We often underestimate the risks, having difficulty in accepting the impermanence of life and that we can all be affected. This behaviour I would name "The Myth of Our Invulnerability." This can obstruct our awareness of real risks and it also amplifies the scope of our reactions. We will also search for explanations to make a critical event more understandable. There is always a risk that we think the fault is our own, or that we become trapped in attempts to find an explanation. There is also the possibility that the media influences our need to find a guilty party. The trauma will also contest the view of the world as a good place in which to live in, being inhabited mainly by good people.

Through knowledge and understanding of our reactions we can obviate and prevent our tendency to flee. This is important because it will better enable us to make use of our previous experience when we go through a crisis. "Try to forget what has happened" is not a good command. The danger is that we do not accommodate our experiences and sorrow. It is important to try to incorporate those experiences, both good and bad.

The Phases of Crisis

Suddenly afflicted by critical events we will have various crisis reactions. All reactions are normal, even if they make us feel uncertain, afraid, and lacking in control. Even if each person reacts differently, there is a pattern that we follow. Our reaction patterns have a survivalist and protective function to help us mobilise our inner physical and psychological resources. The crisis phases vary in intensity and magnitude.

Shock

The Shock Phase (Shutting off) is a primal form of survival that we cannot control at will. Later we can look back on this phase as having been in a dream or state of unreality. Our senses are strongly focused. Thoughts and feelings are often shut off. Seconds can feel like minutes/hours. The shock may remain for several seconds, hours, or days. When we look back on what happened, some of our experiences seem amplified, while others may be very diffuse. Sometimes we question ourselves or have feelings of guilt, for example, of why we did not react more strongly. Then it is important to understand that shock can shut off both thoughts and feelings. Dissociation is a strongly protective function which means, amongst other things, that visual and auditory experiences become split off and "disappear" from consciousness. In certain cases we must redefine the sound sensation of something we had never previously experienced before.

The Reaction Phase (Repetition) is a phase in which we begin more openly to understand and feel what has happened. We begin trying to take in the unmanageableness of reality although we fight against it. It is a period of feelings, reactions and thoughts that come and go. Perhaps mostly in the evenings when there might be stillness and peace. It may be difficult to sleep. Memories and thoughts can bombard us, and we may feel indecisive. Our fears and physical discomforts make us less concentrated and maybe more irritable. It is always difficult to accept what has happened. Although one might not do very much, one might feel tired because so much energy is used in bearing these experiences. Various questions seek answers in an attempt to make the situation more understandable. There are many "What if...?" thoughts that we brood over. There is also a risk in this that we isolate ourselves.

The Processing Phase (*Approaching****)*** means that we try to wrestle with what has happened to us. We can perhaps visit those times and situations that might bring back memories. The pain and the grief remain, but one might begin to try to accept the wounds and scars that were caused. It is of great help to speak to others about what has happened. Each experience contributes an important piece of the puzzle in helping to get a better grip on events. Being able to arrange memorials and other ceremonies becomes an important form of support. Time and space is needed to work through the experiences.

Reorientation phase Perhaps we begin to discover our surrounding world again, as if life had stood still during our crisis, grief and trauma. The outer awareness the crisis caused has now distinctly diminished. This can mean that we are now more alone with our experiences, but also that we might have found greater fellowship with others. Perhaps the crisis has given our life a new perspective and meaning. Perhaps we have become much closer to other people. Our view of ourselves, others, and the world about us has probably changed, for better or for worse. We have a greater vulnerability, but also increased experience and maturity. Nevertheless, we may constantly worry that the same thing can happen again. Slowly we begin to accept everyday life with its potentials, even if it may never be the same again.

Violence

When someone abuses us psychologically or physically, for example by using violence or sexual abuse, the result can cause deep physical and psychological wounds. When we are suddenly attacked, we loose our natural security and control. We become more suspicious, and convinced that the same thing can happen again. – Who can one trust?

Trust and confidence in others may be seriously damaged. Perhaps we begin to experience that which is unfamiliar, unknown and dark, as unpleasant or even dangerous. Perhaps the question of whether justice and goodness really exists arises within us. We may isolate ourselves in order to create temporary protection. Our increased vulnerability creates an uncertainty where both our self-esteem and social networks are threatened. Guilt-imposing thoughts often come to those who have experienced violence. "I should have…" and -"What if I had done so and so instead?" – become reproaches that hack like a scratched grammophone record inside us. It is therefore crucial that every crime victim has the possibility of undergoing crisis therapy, and receiving help in working through that which has happened in order to understand and become aware of their reactions and feelings of guilt. It is of great importance to help those afflicted to understand that there are forces of goodness and strength that can protect and re-enforce a sense of security and safety again.

Fellowship, a feeling of belonging, happiness, laughter, and tears, belong together and create a light in the darkness. Support from relatives, colleagues and friends is very important, especially in case if a trial where we will once again confront the perpetrator. We need to understand that this is a process of heeling that in many cases can take considerable time. Long-term support – practically, legally, emotionally, and even spiritually – is necessary to help us find our security again when violence has threatened our existence.

Crisis Reactions

Understanding the reactions to crisis can fill a preventative and support giving function. Each individual's reaction and sorrow is unique and must be approached with great respect. There are differences and similarities, but all reactions are normal even though they may differ in intensity and magnitude. The reactions come and go, open up and close, sometimes like waves, when we begin to sense and understand what has happened. When we return, in our thoughts and memories to what has happened we are once again in the grip of fear and grief. Grief is a part of everybody's experience, as death is a part of life. Grief and fear can be expressed in different ways, the external events mirroring the internal meaning for the person concerned. Below is a list of diverse reactions that we may feel.

Acute physical reactions. Thought reactions

Difficulty in breathing / Difficulty in concentrating
Palpitations / Limited ability to think logically
Sweating and chills / Difficulty in acting and decision making
Weakness / Disorientation
"Lump in the throat" No appetite / Strong imagery
Diminished hearing / Tunnel vision or distorted memory
Heightened sense experience

Emotional reactions. Behavioural reactions

Feelings of vulnerability / Impaired capacity
Fear – Uncertainty / Difficulty in relaxing
Apathy – Numbness of feeling / Hyperactivity and restlessness
Anger / Rage - Conflict within relationships
Sadness - Feelings of guilt / Crying, wanting to cry
Uneasiness / Isolation, retreating
Suspicion / Difficulty in self-expression, verbal and written
Strong apprehension of new dangers

Social Reactions

Our perception of the value of life can change in either a positive or a negative direction. We may have difficulty in returning to everyday life again. For example, ordinary problems at work and in our surroundings seem unimportant. An increased vulnerability might mean that we become more cautious and have a greater need for control, especially when the threat is invisible. There is a risk of our becoming conflict prone. We might also have a feeling of living more in the present or more intensely. Various conflicts may arise in our daily encounters. There is also the possibility that those around us "forget" what has happened sooner than we ourselves, and make a quicker return to everyday life.

Crisis Handling

Preventative measures

Can we prepare ourselves for a crisis? Both yes and no. Life experiences naturally prepare us to a certain extent, but, at the same time, we can never know how we will react in a given situation. Sometimes we are told to forget what has happened in order to go on with our lives. This tends to have the reverse effect, forcing us to remain with the thoughts and pain connected to the event. It is when we can voluntarily permit ourselves to approach painful experiences that we can free ourselves from them and it is moreover of great importance that we carry our experiences with us into the future. "If we neither look back nor forward we must look out". Also of significance and importance, is the protection of good traditions and even humour that strengthen solidarity because ceremonies and rituals can help us to express what we feel without words. Education and training, within for example the police, rescue service, and healthcare, have shown that mental readiness for difficult events is strengthened by this.

One must, however, be aware that there are always limits to what we can cope with. This especially applies to when children are involved in a crisis. To "utilize" so called evil and painful experiences gives greater readiness in the future. To go through different experiences creating "objective pictures" beforehand, (briefing), is a way to increase mental readiness more systematically.

Urgent Help

This is aimed primarily at helping the afflicted recover from shock (shutting off). It is necessary to create maximum safety and care as quickly as possible, with the helper taking the initiative, as the afflicted party is incapable of decision-making with regard to help.

Never leave anyone alone who is in a state of shock / Try to give warmth (blanket) contact (careful physical contact, eye contact) / Protection from further trauma and the press/ The importance of early contact to inform and gather family, relatives or a personnel group / Strong reactions are a positive sign of recovery from shock / Everyone who experiences a trauma has extra need of security and of someone to trust / If you give information, remember that it is quickly forgotten / Do not forget the so- called strong and responsible person, (for example the leader) who has an initial tendency to reject help for himself/herself.

Long term Help

Great attention may be given to a critical event. When daily life returns to normal there is a risk for feelings of alienation. It is important to have support even in the long-term, and to be aware that this is a process that takes time. It is also vital to support a process in which the afflicted deals with his/her feelings instead of fighting them. The aim is to prevent the person, the feelings, and the event from being isolated.

Family and friends are important resources / Making room for company in which thoughts feelings and impressions can be freely expressed / Try to gather facts in order to combat falsification / Do not take over responsibility for daily problems / Try to counteract isolation / Support various kinds of rituals and ceremonies / In case of death make provision for those nearest to take farewell / Give information and support on common reactions / Remember that grieving takes time / Encourage physical activity, it reduces restlessness / Anniversaries and other memorials/places, help the afflicted tend their grief / Do not forget to find support and emotional outlet for yourself as helper / Find spontaneous or organised forms of dialogue to release the pressure / Try to return to daily routine. Be aware that conflicting feelings will arise / Try not to demand too much of yourself. Give yourself space to pause / Physical activity improves fitness and helps fight restlessness / Remember that everyone needs extra support and encouragement especially in a crisis / Supervision and debriefing reduce the risk of burn-out.

Conclusion

A traumatic experience has an extensive impact on the individual, socially, psychologically and physically and our sensory organs are of vital significance for our survival. In traumatic circumstances hearing and sound can be "distorted" and "disappear" completely from consciousness. The ways our senses coordinate or become damaged depends probably on the type of trauma and the individual's capability of overcoming/working through the crisis. Many interesting future research areas opens up around this subject. With regard to treatment, the consideration of the senses is of great importance.

(translation: Janet Kinnibrugh)

References (Swedish)

Arbetarskyddsstyrelsens tidskrift nr 1 1999, Miljön på jobbet,

Krishantering, 1999

Andersson, Birgitta. Avlastningssamtal (Studentlitteratur 1999)

Cullberg, Johan. Kris och utveckling, (Natur och Kultur 1980)

Dyregrov, Atle. Katastrofpsykologi, (Natur och Kultur 2002)

Fredriksson, Max. Brottsoffer handbok, (Skandia 1996)

George, Mike. Vägen till inre lugn, (ICA-förlaget 1999)

Herting, Anna. Stressens olika ansikten, (Folkhälsoinst. 1999)

Sounds as Triggers

How traumatic memories can be processed by Eye Movement Desensitization and Reprocessing (EMDR)

Kerstin Bergh Johannesson

lic. Psychologist, specialist in clinical psychology, National Centre for Disaster Psychiatry

In December 1991 an aircraft from Scandinavian Airline Systems (SAS) had to make an emergency landing in a field in the countryside north-west of Stockholm just after take off. The plane smashed the trees in its descent. All 129 passengers survived. A few were physically injured. The passengers reported afterwards that the sound of the trees smashing against the airplane remained as vivid auditive impressions. Later on, some of the passengers talked about reminders, that is to say other sounds which were very similar and which became triggers for the experience of the emergency landing. These reminders activated the same type of arousal and emotional reactions as the original reactions at the time of the accident.

A threatening incident, as the one described above, which is sudden and unexpected, is experienced differently by different people. Most people react initially with strong arousal, followed, for some time by sensory re-experiencing, like pictures, sounds, taste or body sensations, but also accompanied by elevated tension and anxiety and maybe a lack of emotional balance. For most people these reactions will decrease after a shorter period, but for some they will remain. It seems as if these persons cannot process their impressions, and the unprocessed memories are stuck in the mental memory system. Anxiety arises when the individual is reminded of the incident, and because of this fact, tries to avoid everything that might remind them of what happened. An invisible wound has emerged, which does not seem to change over time. What happened in the past continues as an everlasting presence. This is the nature of the traumatic memory, which is typically dominated by perceptual characteristics, pictures, sounds, scents or body sensations. Often the memory is fragmented, but the fragments can be very vivid. The fragmented memory is associated with strong negative feelings. Some parts of the incident might be dissociated, that is, they cannot be retrieved in a voluntary way. If this condition lasts for more than a month, the person might have developed what is called a posttraumatic stress syndrome, PTSD.

Persons can be reminded of a traumatic experience by so called triggers. These triggers consist of external or internal reminders, which are related to the original incident. Triggers can consist of verbal stimuli, sounds, thoughts or pictures. The reminders will cause the person to re-live the traumatic incident, as if it happened again. This re-living can be characterised by sensory stimuli and might be experienced as a video clip, as pictures, or as body sensations. Sometimes re-living might have a more auditive quality, like words, or as in the example above, noise or even inner voices.

Findings suggest that the right hemisphere of the brain is important for traumatic memories. A study by Pagani, Högberg et al (2006) demonstrated that clients with PTSD, who had auditive trauma reminders, had an increased blood flow in the right brain hemisphere when they were compared to a group who had not developed PTSD.

Treatment for PTSD

Standard psychotherapeutic treatments for PTSD and traumatic memories usually include some type of exposure to the traumatic experience, either in vivo or, if more appropriate and maybe more common, in an imaginary mode. It is also common that the treatment model includes investigating and processing maladaptive cognitions of the self, which might have developed from the negative experience.

Eye Movement Desensitization and Reprocessing (EMDR) is a psychotherapeutic approach for reducing distress after traumatic experiences, which is disturbing in everyday life. Treatment is focuses on how trauma affects present functioning. EMDR is an evidence-based method for treating chronic post-traumatic stress syndromes (Bisson et al 2007). The method has been demonstrated to be equally effective as exposure-based therapies

(Spates et al 2009). EMDR can also be applied for acute PTSD. EMDR has also been used for other types of problems like anxiety and panic attacks, traumatic grief, reactions to physical illnesses and many other conditions that are associated with distressing experiences.

EMDR is a therapeutic approach that emphasises the brain's information processing system and how memories are stored. The adaptive information-processing model posits the existence of an information processing system that assimilates new experiences into already existing memory networks. These memory networks are the basis of perception, attitudes and behaviour.

Problems arise when an experience is inadequately processed. Current symptoms are viewed as resulting from disturbing experiences that have been encoded in state-specific, dysfunctional form (Shapiro, 1995, 2001, 2007, 2008). Even if the traumatic incident took place a long time ago, it will be experienced once again together with the emotions and sensations that were experienced at the original time. The core goal of EMDR involves the transmutation of these dysfunctionally stored experiences into an adaptive resolution, which promotes psychological health. EMDR aims at activating the ability to handle the distress of traumatic memory and to decrease disturbing thoughts and emotions. It can also help the patient to think differently about himself in relation to the traumatic memory.

EMDR integrates elements of many psychotherapeutic orientations, such as psychodynamic, cognitive behavioural and body-centred orientation. Treatment follows a structured protocol. The method was originally developed for adults, but it is easily adjusted for children. Treatment is usually focused on the individual, but applications have been made for group treatment.

EMDR uses an eight-phase approach. During EMDR processing, the patient is asked to focus on a specific traumatic memory and to identify the distressing image that represents the memory, the associated negative cognition, an alternative positive cognition, to identify emotions that are associated with the traumatic memory, and to identify trauma-relevant physical sensations and their respective body locations. This process is quantified by use of subjective indicators and measures. After these preparations, the patient is asked to hold the distressing image in mind along with the negative cognition and associated body sensations, while tracking the therapist's fingers back and forward across the patient's field of vision in rhythmic sweeps during approximately 20 – 40 seconds. The patient is then asked to take a break and to give feedback to the therapist of any changes in images, sensations, thoughts or emotions that might have occurred. This process is repeated and continued until the client no longer experiences any distress from the traumatic memory. Bilateral tactile stimulation or sounds can be used as an alternative to eye movements. If EMDR is effective for the particular patient, this will show within one to two treatment sessions. A limited number of sessions are often enough for problems after a single trauma. However, length of treatment depends on the complexity of the traumatic experiences.

It is not yet established how and why EMDR is effective, but there are some hypotheses. One line of thinking stresses the fact that processing is connected with a doubled focus. The client is encouraged to think of the memory and simultaneously follow the moving hand of the therapist. Possibly this could establish a state of mindfulness, which creates a more open mind, stimulating a free process of associations which could open up for other perspectives. Some authors have described this as changing the orienting response in the mind. The method is also characterised by a dosed exposure to the traumatic content, which might be benevolent for the client, avoiding him or her being overwhelmed.

Processing with EMDR can be emotionally powerful. Only therapists licensed to work with psychotherapy and who have a specially approved EMDR-training should therefor perform EMDR-treatment.

References

Bisson J, Andrew M. Psychological treatment of post-traumatic stress disorder (PTSD). Cochrane Database of Systematic Reviews 2007, Issue 3

Pagani M, Högberg G, Salmaso D, Tärnell B, Sanchez-Crespo A, Soares J, Aberg-Wistedt A, Jacobsson H, Hällström T, Larsson SA, Sundin O. (2005). Regional cerebral blood flow during auditory recall in 47 subjects exposed to assaultive and non-assaultive trauma and developing or not posttraumatic stress disorder.Eur Arch Psychiatry Clin Neurosci. Oct; 255(5):359-65.

Solomon, R & Shapiro, F (2008). EMDR and the Adaptive Information Processing Model. Journal of EMDR Practice and Research; 2 (4): 315-325.

Spates, C.R., Koch, E., Cusack, K., Pagoto, S. & Waller, S. (2009). In Foa, E.B., Keane, T.M., & Friedman, M.J., (eds.), Effective treatments for PTSD: Practice Guidelines of the International Society for Traumatic Stress Studies (pp279-305). New York: Guilford Press.

Shapiro, F. (1995). Eye Movement Desensitization and Reprocessing: basic principles, protocols and procedures. New York: Guilford Press.

Shapiro, F. (2001). Eye Movement Desensitization and Reprocessing: basic principles, protocols and procedures (2nd Ed.). New York: Guilford Press.

Shapiro, F. (2007) EMDR and case conceptualization from an adaptive information processing perspective. In F. Shapiro, F. Kaslow, & L. Maxfield (Eds.), Handbook of EMDR and family therapy processes (pp 3-36. New York: Wiley.