Stress and music performance anxiety

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This work is dedicated to
André Flour, Maria 'Trix' Hendrickx, and Marie-Louise Levecque,
apostles and strong believers in, respectively,
knowledge, science, and simplicity.

Contents

Abstract

Acute and chronic stress, as well as accompanying changes of the hypothalamic-pituitary-adrenal (HPA) axis, affect cognitive processes, including memory. In professional musicians occupational stress and music performance anxiety (MPA) are a major source of concern during a musical career, whereas a *boost* is to a certain extent necessary for a musical performance.

A protocol was successfully designed to induce acute stress in healthy students while measuring electro-encephalography (EEG). The protocol allowed for delineating the relationship between acute stress and sensory memory of different sound features. Acute stress attenuated this type of memory, particularly for sound duration. In addition, the protocol allowed for distinguishing between acute stress and mental workload, affecting the brain at different topographical sites.

Chronic stress was studied in tinnitus patients. Among these, the HPA axis's feedback mechanism showed a greater and longer-lasting sensitivity, either as a consequence of chronic tinnitus or as a predisposing factor. In addition, the patients showed a greater sensitivity to auditory system stress.

A survey study investigated the stress and MPA experience of professional musicians. Debilitating MPA and *boost* were found to be not opposite but rather only distinct factors. In addition, debilitating MPA with a low career impact was found to be still under the influence of performance confidence and *boost*, with debilitating MPA with high career impact being related to health factors. Furthermore, debilitating MPA was also found to be related to perceived pressure, with *boost* being related to perceived support, providing possible anchor points in battling MPA. Identifying with one's instrument was revealed as another possible anchor point. Feeling 'in unison' with the instrument proved to be most beneficial.

Tiivistelmä

Akuutti ja krooninen stressi sekä niiden yhteydessä muuntuva hypotalamus-aivolisäke-lisämunuais –akselin toiminta vaikuttaa kognitiivisiin toimintoihin ml. muistiin. Ammattimuusikoilla työperäinen stressi ja esiintymisjännitys muodostavat karikoita urakehitykselle. Esiintymisjännityksen "kutkuttavaa" läsnäoloa toisaalta tarvitaan esiintymisen onnistumiseksi.

Väitöstutkimuksissa kehitettiin tutkimusasetelma akuutin stressin aikaansaamiseksi terveillä opiskelijoilla. Asetelmassa tutkittiin kuulomuistin toimintaa erilaisten äänten piirteiden uhteen stressin aikana EEG-mittausten avulla. Akuutti stressi heikensi kuulomuistin toimintaa erityisesti äänten keston suhteen. Lisäksi asetelmassa pystyttiin erottamaan akuutin stressin ja yleisen kognitiivisen kuormituksen aivovaikutukset.

Kroonista stressiä tutkittiin tinnituspotilailla. Heillä hypotalamus-aivolisäke-lisämunuais –akselin palautemekanismi toimi pidempään ja herkemmin joko tinnituksen seurauksena tai sille altistavana tekijänä. Lisäksi potilaat olivat herkempiä kuuloaistissa ilmenevälle stressille.

Kyselytutkimuksella selvitettiin stressin ja esiintymisjännityksen kokemusta muusikkojen joukossa. Suoritusta heikentävä ja sitä parantava esiintymisjännitys eivät olleet vastakkaisia mutta selvästi erillisiä ilmiöitä. Suoritusta heikentävä esiintymisjännitys oli yhteydessä koettuun paineeseen, sen sijaan suoritusta parantava esiintymisjännitys oli yhteydessä koettuun tukeen. Ilmeni myös, että koettu vahva yhteyden tunne omaan soittimeen vähensi esiintymisjännityksen kokemusta.

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Veerle Simoens

List of original publications

This thesis is based on the following articles, which are referred to by their roman numerals in the text.

I   Simoens, V.L., Istók, E., Hyttinen, S., Hirvonen, A., Näätänen, R., & Tervaniemi, M. (2007). Psychosocial stress attenuates general sound processing and duration change detection. *Psychophysiology,* 44(1), 30–38.

II   Simoens, V.L. & Hébert, S. (2012). Cortisol suppression and hearing thresholds in tinnitus after low-dose dexamethasone challenge. *BMC Ear, Nose & Throat Disorders,* 26, 12:4.

III   Simoens, V.L., Puttonen, S., & Tervaniemi, M. (in revision). Are music performance anxiety and performance *boost* extremes of the same continuum?: A questionnaire study among musicians.

IV   Simoens, V.L. & Tervaniemi, M. (in press). Musician-instrument relationship as a candidate index for professional well-being in musicians. *Psychology of Aesthetics, Creativity, and the Arts.*

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Abbreviations

ACTH	adrenocorticotropic hormone
CRH	corticotropin-releasing hormone
EEG	electroencephalography
EOG	electrooculogram
ERP	event-related potential
GR	glucocorticoid receptor
HPA axis	hypothalamic-pituitary-adrenal axis
MMN	mismatch negativity
MPA	music performance anxiety
MR	mineralocorticoid receptor
RMS	root mean square
SAM axis	sympathetic-adrenal-medullary axis

1 Introduction

1.1 Stress and its physiological pathways

Originally, the term 'stress' was used to explain forces that can put strain on a structure in such a way that a piece of metal can shatter like glass if a certain threshold is reached. Our current concept of stress developed from the work of Hans Selye, (1936) who first described stress as 'general adaptation syndrome'. Even in our day-to-day conversations, 'stress' is now interpreted as an imbalance between external forces or loads and an individual ability to cope with or resist those external forces (Lazarus, 1993). In humans today, potent stressors commonly involve novelty, unpredictability, threat to the ego, or a sense of decreased control (Dickerson & Kemeny, 2004). The subjective nature of these stressors implies that what is perceived as stressful is not the same for every individual.

When under stress, two pathways are triggered; the first line sympathetic-adrenal-medullary axis (the SAM axis) and the second line hypothalamic-pituitary-adrenal axis (the HPA axis). The SAM axis gives rise to an elevation of circulating adrenaline and noradrenaline released from the medulla of the adrenal glands. The HPA axis gives rise to an elevation of circulating glucocorticoids, such as the stress hormone cortisol, from the cortex of the adrenal glands. This increased release of glucocorticoids is set in motion higher up the axis by an activation of neurons in the hypothalamus, discharging the corticotropin-releasing hormone (CRH), which in turn triggers secretion and release of the adrenocorticotropic hormone (ACTH) from the pituitary gland.

Circulating glucocorticoids bind with two kinds of receptors: the high-affinity mineralocorticoid receptor (MR) and the lower affinity glucocorticoid receptor (GR). The HPA axis is a closed-loop system, which is subjected to a tight negative feedback control mediated by these two receptor types. The HPA axis tone, assessed in basal cortisol levels, is regulated by the MR receptors, which are exclusively present in the limbic system (de Kloet et al., 2005). Stress responsiveness is determined by the GR receptors, which are more critical for terminating the HPA axis stress response, and are located in subcortical structures (such as hypothalamic nuclei and the hippocampus),

cortical structures (such as the prefrontal cortex), as well as the inner ear (Birmingham et al., 1984; Reul & de Kloet, 1985; Marin et al., 2010; Meltser & Canlon, 2011).

1.2 Pre-attentive sensory memory

1.2.1 Definition

Sensory memory (or echoic memory) is an accurate memory representation of the auditory, visual, and somatosensory stimuli that lasts for a brief duration of up to several seconds (Näätänen et al., 1992; Jääskeläinen et al., 2011; Sams et al., 1993). Behavioural studies suggest that sensory memory for auditory and visual stimuli consists of two components; 1) a highly transient and accurate representation of elementary physical stimulus features (in the order of hundreds of milliseconds), and 2) a longer-duration storage that contains more abstract features of the stimuli (from several seconds up to dozens of seconds; Cowan, 1995; Jääskeläinen et al., 2011). An accurate representation of stimuli in sensory memory allows the individual to detect changes in the sound environment. This detection can even take place automatically, without conscious realization on the part of the individual. In Study I, this automatic change detection for different stimuli features was targeted, taking place prior to attentional processes. This type of memory is thus called pre-attentive sensory memory, and evidence for such memory can be detected as early as 150 ms after stimulus onset.

1.2.2 Neural correlates

The neural correlates of pre-attentive memory processes studied in this thesis were measured with electroencephalography (EEG). This method allows non-invasive measurement of electrical neural activity in the brain with a detailed time scale in the order of milliseconds. Electrodes attached to the scalp pick up electrical potentials, which are compared to those registered by a reference. Those potentials are generated by synchronized post-synaptic activity of large groups of pyramidal cells. This activity

can then be visualized over a period of time with a precision of milliseconds. In order to investigate individual cognitive processes, event-related potentials (ERPs) are attained by the use of averaging techniques.

Sensory memory can be indirectly assessed by means of the mismatch negativity (MMN), a negative ERP component appearing around 150 ms after stimulus onset. The auditory MMN reflects the operation of a pre-attentive memory-based comparison mechanism that responds to any discriminable change in regular auditory input (Schröger & Wolff, 1998; Näätänen et al., 2011). Its generator is believed to be an automatic cortical change detection process that finds differences between current sounds and the representation of regular aspects of the sound environment created by preceding sounds (Näätänen et al., 2005). The MMN is calculated as the response to a sudden change in the sound environment, either in simple stimulus features or in more abstract rules (deviant), subtracted from the response to the common stimuli in the sound environment (standards).

The mechanisms of sensory memory have been linked to neuronal adaptation (Ulanovsky et al., 2003; Jääskeläinen et al., 2011). Neuronal adaptation is the decline over time of the neuronal responses during repeated sensory stimulation. The MMN has been shown to have two sets of neuronal generators. One major set is temporal, located in the vicinity of the primary auditory cortex, and a second minor set is frontal, involving mainly the right hemisphere (Giard et al., 1990; Picton et al., 2000). Adaptation found in auditory cortical areas is often stimulus-specific (Condon & Weinberger, 1991; Ulanovsky et al., 2003). This stimulus- specific adaptation of even single neuron firing was observed with repetition of frequent standard sounds (Ulanovsky et al., 2003). Based on this scientific evidence, several authors have suggested that this form of adaptation is at the basis of sensory memory, and thus also of the MMN (Ulanovsky et al., 2003, 2004; Jääskeläinen et al., 2011).

However, the adaptation theory of Jääskeläinen et al. (2004, 2011) is based on the proposition by May and Tiitinen (2004, 2010) that the MMN is a product of an N1 difference wave (a negative ERP component around 100 ms after stimulus onset, related to stimulus detection), which emerges in the subtraction procedure used to visualize and quantify the MMN. In contrast to this view, Näätänen et al. (2005) provided evidence

that this might not be the case, but rather that the presence of a memory representation of the standards is required for the elicitation of the MMN.

Combining the two theories, neuronal adaptation to the standards and change detection of the deviants might be two distinct mechanisms. This suggestion is supported by a study comparing younger adults with older ones by Fabiani et al. (2006). In this study, brain responses to standards were quickly suppressed in younger adults, but were more persistent in older ones. The brain responses to deviants, however, were largely unaffected in the elderly.

1.3 Acute and chronic stress: Effect on memory and cognitive functioning

The HPA axis is to a large extent orchestrated by the hippocampus, the prefrontal cortex, and the amygdala, which in turn seem particularly sensitive to the effects of stress (Ulrich-Lai & Herman, 2009; Radley & Sawchenko, 2011). These brain structures are critically involved in evaluating a situation and selecting an appropriate response (involvement of the prefrontal cortex), taking into account the emotional content of the situation (involvement of the amygdala) in relation to past experiences (involvement of the hippocampus, Marin et al., 2010). Mechanisms that create the response to both acute and chronic stress include neuromorphological changes in these highly plastic brain structures (Gorman & Docherty, 2010). Dendritic branches of the neurons can extend or retract, and small protrusions can emerge, disappear, or change in shape and size. The density, stability, and morphology of these protrusions can affect brain connectivity and neuronal excitability (Leuner & Shors, 2012). Some of these changes occur within seconds or min and can therefore lie at the basis of cognitive changes during acute and chronic stress in order to allow an individual to react to a stressful event in an adaptive or maladaptive manner.

Most studies concerning stress and memory have focused on working memory and longer types of memory, but not sensory memory. However, a weakness in such early stages as pre-attentive sensory memory could manifest itself in deficits in later and longer stages of memory. Several authors found that both endogenous and exogenous

acute elevations in the stress hormone cortisol could impair working memory and memory encoding (Lupien et al., 1999; Schoofs et al., 2008). Lupien (2000) later proposed a closed-loop model in which increased basal cortisol levels would eventually lead to difficulties in discriminating relevant (potentially threatening) information from irrelevant (non-threatening) information in the pathogenesis of chronic stress and several related disorders. Sensory memory within the auditory cortices would naturally be the first step in the discrimination of threatening versus non-threatening sounds.

1.4 Stress, anxiety, and music performance anxiety

Whereas stress is generally defined as an environmental demand that requires a coping response, anxiety is seen as the emotional reaction evoked in an individual in response to a stressful situation that is perceived as threatening or contains demands that are perceived as excessive or unachievable (Gaudry & Spielberger, 1971). Arousal, activation, and alertness are synonymous terms that may imply a negative as well as a positive experience (Kenny, 2011). They refer to all levels in the spectrum from deep sleep to intense excitement or fear.

An elevated state of arousal can be beneficial or detrimental to a musical performance. Already when Selye introduced the concept of stress (Selye, 1955), he distinguished between two different types of stress: 'eustress' (*good stress* or adaptive stress) and 'distress' (maladaptive stress). If a musician is experiencing 'eustress' or a *boost*, the accompanying high level of arousal can be reported as a euphoric chill of excitement, enhancing the musical experience. On the other hand, if the musician is experiencing the 'distress', the elevated arousal level can be seen as somatic anxiety (Kenny, 2011). Glucocorticoids such as cortisol are to a certain extent even necessary for optimal cognitive processing (Marin et al., 2010). If no exogenous glucocorticoids are administered, e.g. memory performance can be enhanced by the endogenous glucocorticoid release induced by stress. Such an adaptive effect of stress on performance is also found in musicians, who often perform better when they experience the *boost* of moderate stress. In the complete absence of this *boost*, poor mental and physical activation or lethargy might occur (Wilson, 2002; Papageorgi et al., 2007;

Marin et al., 2010). The most common model of stress (as well as music performance anxiety) and cognitive performance levels (as well as musical performance) is the inverted U-shape model or the Yerkes-Dodson law, in which low levels of arousal result in poor performance (maladaptive), medium levels of arousal are considered optimal and result in a *boost* (adaptive), and very high levels of arousal (maladaptive) result in poor performance due to an excess of mental and physical activation (Wilson, 2002; Papageorgi et al., 2007). However, the model has been criticized for its simplicity. Kenny (2011) describes several aspects influencing the relationship between arousal and performance that have not been incorporated in this model, such as the performer's level of state/trait anxiety and its interaction with task mastery. Furthermore, musicians differ in their optimal arousal levels which are also dependent on the musicians' experience.

The definition of anxiety is less well defined and has changed over the years. However, the often cited meaning is that anxiety is a complex, learned, emotion in which fear is combined with other emotions such as anger, shame, guilt, and excitement (Izard, 1977). It is considered closely related to a trait (Kenny, 2011). Anxiety often emerges after stressful experiences. Sometimes it is adaptive, preparing the individual for future similar events. Other times the anxiety is maladaptive if it is prolonged or exaggerated over time, possibly leading to anxiety disorders or related illnesses. The hippocampus, prefrontal cortex, and amygdala are considered key candidates for the mediation of anxiety (Leuner & Shors, 2012). Not only are these structures involved in the regulation of the HPA axis and prone to changes induced by stress, but also they are associated with the neurocircuitry of anxiety in humans (Mathew et al., 2008; Shin & Liberzon, 2010; Kim et al., 2011).

Tinnitus is thought to be an affliction related to chronic stress and anxiety manifestations (Bartels et al., 2008; Langguth et al., 2011; Hébert et al., 2011). Subjective tinnitus (commonly called 'tinnitus') is the perception of sound in the ears or head in the absence of any external sound. Chronic stress is known as a trigger or co-morbidity of tinnitus. Even though this notion has been mainly based on anecdotal and retrospective reports, it has been traditionally taken for granted (e.g., Tyler, 2000). Additionally, large population studies have established that emotional exhaustion and long-term stress are predictors of hearing disorders, including tinnitus (Hasson et al., 2010, 2011). Tinnitus can thus be taken as an appropriate model of chronic stress.

Furthermore, the population of tinnitus patients is a well-defined group, often without any serious co-morbid condition. This is in contrast to many other conditions associated with chronic stress, such as post-traumatic stress disorder or chronic pain. Brain imaging studies have also shown a link between the limbic system (involved in emotions, including the amygdala and the hippocampus) and auditory structures (Lockwood et al., 1998; Vanneste et al., 2010; Leaver et al., 2011). Besides the evidence from brain imaging studies, other confirmation of a link between tinnitus and stress comes from studies concerning the HPA axis (Hébert et al., 2004; Hébert & Lupien, 2007; Heinecke et al., 2008).

Another affliction related to chronic or repeated stress exposure is music performance anxiety (MPA) in musicians. In clinical settings, MPA as such is not defined by the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR, 2000). MPA is, however, briefly mentioned under differential diagnosis, where it is state that MPA should not be diagnosed as a social phobia unless the anxiety or avoidance leads to clinically significant impairment or marked distress. Performing music usually takes place in front of an audience, more often than not with other musicians, and therefore also has a social component (Papageorgi et al., in press). However, MPA in musicians has several characteristics that distinguish it from a social phobia and might therefore be considered a specific subtype of social phobia (Powell, 2004). Similarities and differences between social phobia and MPA are still under debate (contradicting results in Powell, 2004; Clark & Agras, 1991; Cox & Kenardy, 1993; Steptoe & Fidler, 1987; Osborne & Franklin, 2002). Music performance anxiety is generally believed to be a serious problem among professional musicians. According to a questionnaire survey by the International Conference of Symphony and Opera Musicians (ICSOM) in the U.S., 24% of the 2,212 responding musicians frequently suffered a severe form of music performance anxiety (1 item to assess MPA, Fishbein et al., 1988). In the Netherlands, 59% of orchestra musicians tested also reported music performance anxiety severe enough to impair their performance and/or personal functioning (van Kemenade et al., 1995). In a survey of 56 orchestras, James (1998) found that as many as 70% of the musicians were affected by music performance anxiety severe enough to impair the musical performance.

1.5 Effect of identification with the musical instrument on MPA and well-being

One aspect of musicianship that seems to influence professional well-being in terms of MPA and related factors according to anecdotal reports is identification with one's musical instrument. Proficient musicians often report that they feel their instrument to be a part of themselves.

Previous research on this topic is, to our knowledge, virtually non-existent. However, Nijs et al. (in press) suggest a theoretical model stating that the musician's perception of being fused with the instrument is grounded in a subjective experience of *flow*. When musicians are not hindered by anything such as technical difficulties or debilitating MPA, they will be able to play the music exactly the way they intend. By achieving this performing state, they are more likely to achieve the often referred to experience of *flow* (Csíkszentmihályi, 1990). Characteristics of this subjective state include intense and focused concentration on the task, loss of awareness of oneself as a social actor, a sense of control, and the experience of the task as rewarding in itself (Csíkszentmihályi & Nakamura, 2002). The *flow* state would be very advantageous to a musician: It would stimulate enjoyment and engagement (and thereby motivation) in the performance and function as a reward signal to promote practice (Csíkszentmihályi & Csíkszentmihályi, 2002). The repeated experiences of the short-term *flow* experiences would eventually lead to the long-term subjective experience of being merged with the instrument (Nijs et al., in press). Following this reasoning, if a musician is hindered by anything, then the *flow* state is not likely to occur, and a separation between musician and instrument will remain.

Even though expertise is most often cited as the variable that determines whether a musician will achieve *flow* (de Manzano et al., 2010; Leman, 2007), there are other factors that could disrupt the musician's performance, such as debilitating MPA, poor general health, or inefficient coping mechanisms for handling the demands of the profession. Musicians are regularly exposed to high levels of occupational stress. Besides MPA, these occupational stressors include job insecurity, financial insecurity, irregular working hours, frequent traveling, social tension with music stand partners or other peers, exposure to noise, and the combination of lack of control with high

demands, especially in larger orchestras (Hagglund, 1996; Steptoe & Fidler, 1987; Hamilton et al., 1995; Panasuraman & Purohit, 2000; Mäkirintala, 2008; Theorell, 2001).

2 Aims

The joint aim of the studies in this thesis was to investigate the effects of acute and chronic stress, as well as MPA, on human behaviour, on cognitive and endocrine processes, as well as on occupational repercussions. The specific research questions are listed below.

What is the effect of acute stress on pre-attentive sensory memory?
Prior research on this topic often induced acute stress by use of cold pressure (closely related to pain), challenging mental tasks, or simply the administration of exogenous glucocorticoids. Study I was designed to create a more naturalistic acute stress experience. In addition, the study aimed at disentangling the effects of acute stress from the effects of a challenging mental task.

What is the effect of chronic stress (stress) on the HPA axis sensitivity?
In Study II, the suspected link between chronic stress and tinnitus was further explored by studying the sensitivity of the HPA axis in tinnitus patients. Both basal stress levels (MR) and the HPA axis response (GR) to a challenge (low-dose dexamethasone) were tested.

   In addition, the study sought to measure the hearing and discomfort thresholds in tinnitus patients and healthy controls. Especially the GR have been found in abundance in the inner ear, whereas their function at that location has remained unclear up to now. Previous studies provided some evidence that cortisol increase exerts a direct influence on hearing. However, no studies so far have examined the effects of experimental manipulation of cortisol suppression (obtained with the dexamethasone challenge test) on hearing thresholds in humans.

Is the positive boost the opposite of debilitating MPA?
A first aim of Study III was to explore whether MPA and the *boost* are indeed part of the same continuum, as predicted by the commonly cited U-shape models. If so, the two types of MPA should be manifestations of an identical phenomenon with different degrees of strength and thereby different consequences for musical performance. To our

knowledge, none of the MPA questionnaires target the truly debilitating aspect of MPA, and only one study so far has focused on the positive effect of MPA on musical performance in addition to the negative effect (Wolfe, 1989). However, the tools used in that study are somewhat questionable.

What factors contribute to the experience of MPA in musicians?
Even though MPA *per se* is not necessarily bad for musical performance, debilitating MPA is by definition harmful to it. A second goal of Study III was to explore which factors could be of importance in a musical career's downward spiral set in motion by debilitating MPA.

Does the type of identification with one's musical instrument affect MPA and general professional well-being?
One of the reflections of professional well-being in musicians could be the relationship they have with their instrument. Without the instrument, the musician cannot perform. This dependency and many years of 'collaboration' must undoubtedly lead to a complex relationship that is sensitive to alterations whenever the musician's well-being is jeopardized. To our knowledge, this relationship has not yet been empirically studied, even though it is often referred to by musicians. The main goal of Study IV was twofold. First, we explored whether the relationship of the musician with his or her instrument/voice would manifest relevant factors for professional well-being. Second, we wished to indicate whether or not the feeling of unification with a musical instrument is truly advantageous.

3 Methods

3.1 Participants

The participants in Study I were healthy male university students with normal hearing (Table 1). Only male students were recruited in order to rule out the hormonal influences of a menstrual cycle on salivary cortisol (for a review, see Kudielka & Kirschbaum, 2005). The participants were free of jetlag, relevant diseases, medication, and life habits that influence cortisol levels.

For Study II, tinnitus patients and healthy controls were recruited. All tinnitus patients reported chronic tinnitus for at least six months, but did not wear a hearing aid. The groups were similar in age, educational level, and body mass index. All participants were in good physical and mental health and did not report any disease, medication, or habits that could interfere with the HPA axis, such as the use of beta-blockers or antidepressants, diabetes, uncontrolled hypo- or hypertension, experiencing a jet lag or having undergone surgery in the past six months, or having a body mass index of 30 or more. All women in the study were postmenopausal, and two of them (one in each group) were taking hormone replacement therapy.

For Studies III and IV, a questionnaire survey was conducted. The questionnaires were distributed among music schools and academies, professional orchestras, bands, choirs, operas, a record company, and two restaurants in Finland. 116 students and 204 professionals completed the questionnaires. Ten of the 116 students were not yet sure if they would pursue a career as a professional musician. The majority of musicians performed mainly classical music (83.1%). The remaining musicians reported performing genres such as pop/rock (8.1%), jazz (3.1%), folk/ethnic (1.2%), other (2.5%), or undetermined (1.9%).

Studies I, III, and IV were approved by the ethical committee of the former Department of Psychology (currently part of the Institute of Behavioural Sciences), the University of Helsinki. Study II received ethical permission from the ethical committee at the Institut Universitaire de Gériatrie de Montréal, Canada. Participants in Studies I and II received a small financial compensation for their contribution. All participants in

all studies signed informed consents, and all experiments respected the Declaration of Helsinki formulated by the World Medical Association.

Table 1. Participants in Studies I-IV

Study		n	% males	Mean age	Age range
I		21	100.0	25.8 ± 3.3	20 - 35
II	Tinnitus	21	52.4	65.7 ± 7.1	52 - 80
	Controls	21	47.6	65.7 ± 8.7	50 – 78
III – IV		320	42.5	35.9 ± 12.2	16 - 64

Note: Mean age in years ± S.D. Age range in years.

3.2 Questionnaires

In Study II, the severity of subjective tinnitus was assessed in tinnitus patients with a French version of the Tinnitus Reaction Questionnaire (Wilson et al., 1991). As depression is a common co-morbidity in tinnitus patients, which also has a profound influence on the HPA axis, the Beck Depression Inventory II (Beck, 1997) was used to test for symptoms of depression in both the tinnitus patients and the healthy controls.

Studies III and IV both analyzed the results of a questionnaire survey. Table 2 gives an overview of the questionnaires comprised of a distributed questionnaire packet, available in Finnish, Swedish, and English.

To categorize the participants according to their identification with their instrument/voice (Study IV), section 18 (Identification, Table 2) asked the participants to complete the sentence 'When I perform, I feel… 1) that it's really me as a person in front of the audience rather than my instrument', 2) 'protected/hiding behind' my instrument/voice', 3) that 'my instrument/voice is an obstacle to overcome between me and the audience', or 4) 'so united with my instrument/voice that there is no difference between us'. These options were chosen on the basis of anecdotal evidence, as, to our knowledge, there is no empirical data to date on this topic.

Table 2. Questionnaires used in Studies III-IV

Questionnaire	Description
1- Informed consent	
2- Circumstances	Circumstances in which the questionnaire was completed
3- Personal information	Age, gender, smoking, alcohol consumption, physical exercise
4- Sleep quality	Jenkins 4-item Sleep Evaluation Scale (Jenkins et al., 1988)
5- Critical life events	Encounter and impact of life events
6- Mental distress	12-item General Health Questionnaire (Goldberg & Williams, 1988)
7- Social phobia	Social Phobia Inventory (Anthony et al., 2006)
8- Musical background	Instruments, starting age and age of first performance, musicians in the family, student or professional, music as their major income, main genre of education and majority of performances, number of (solo) concerts and competitions, percentage of time distributed over different professional tasks and ranked according to stressfulness
9- Confidence	Confidence in own musical performance
10- Performance	To whom musicians aimed performances; how strongly they felt evaluated by different parties
11- Pressure & support	Rating of perceived pressure and support by different parties
12- Statements	17 statements related to performing, including: 'Stage fright has had a negative effect on my musical career/study'
13- Coping	Coping strategies and effectiveness
14- MPA	Performance Anxiety Questionnaire (Cox & Kenardy, 1993)
15- MPA evolution	More, less, or equal to earlier
16- MPA factors	Debilitating cognitive and somatic MPA manifestations, *boost*, self-oriented perfectionism, avoidance, performance confidence, acting as coping, fear of negative evaluation, post-event processing
17- Stressfulness	Retrospective evaluation of stressfulness of different performing settings
18 - Identification	Identification with one's instrument

Note. The 17 statements related to performing included 'I have stage fright' and 'Playing music is still as much fun as it used to be'. Coping strategies included alcohol/drugs/smoking, praying/lucky charm/superstition, thinking positively, practicing, relaxation exercises, talking to teachers/friends about the performance, medication, or other.

3.3 Stimuli

In Study I, four blocks of stimuli (each lasting 17 min) were presented. The paradigm, adopted from Näätänen et al. (2004), consisted of frequently repeated standards alternating with five types of deviants, which differed from the standards in frequency, duration, location, intensity, or the presence of a gap (Fig. 1). The stimuli were not to be attended but were presented to the participants while they were engaged in various tasks.
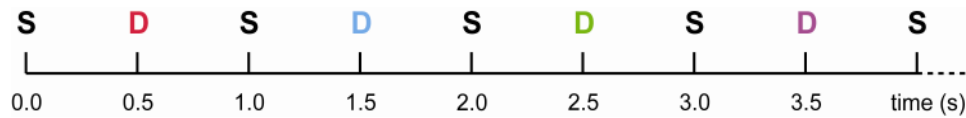
Fig 1. Stimuli presented in Study I, according to the multi-feature paradigm (Näätänen et al., 2004). Standards (S) were alternated with different types of deviants (D).

Whereas in the previous study the stimuli were presented at about 40 dB above the hearing threshold, Study II required a more precise measure of the threshold. Both hearing and discomfort thresholds were assessed in a sound-proof booth. The hearing threshold was assessed for half-octave frequency steps from 250 to 8000 Hz using an adaptive automated procedure. Discomfort thresholds were assessed for frequencies 1 kHz, 2 kHz, and 4 kHz and was determined at the level at which the participants judged the sound as 'too loud'.

3.4 Experimental procedures: stress manipulations

Study I was designed to compare sensory memory processes under normal circumstances to those under acute stress. To induce stress, the Trier Social Stress Test (Kirschbaum et al., 1993) was adapted for simultaneous EEG recording. The experiment started with two consecutive blocks of EEG measurement during which the participants attended to a silent subtitled video of their choice (Video 1 and 2: low in stress, low in mental workload, Fig. 2). The stress protocol was then initiated by an explanation of and preparation for a job interview, during which the participants were asked to prepare a five-minute monologue in English in front of a camera and a three-member jury. They were told that one of the jury members was an expert in non-verbal communication. After the protocol was explained, the participants were left alone for 10 to 18 min. Not yet knowing which job to apply for, they were asked to use this time to reflect on their general job-related qualities and experiences. Following this preparation time, a third block of EEG measurements was taken while the participants attended information (presented at a slow pace) about the job to be applied for. Immediately afterwards, the camera and the jury entered the shielded room, and an additional light was pointed at the participants. Aside from information about the time remaining, the

participants received no feedback of any kind during the job interview (Job: high in stress, low in mental workload). After the interview, the jury member identified as a specialist in non-verbal communication remained to observe the participant inside the shielded room while a demanding IQ test was presented on the screen during the final EEG recording (IQ: high in stress, high in mental workload), with the spotlight and camera still in place. After the experiment, the participants were debriefed.

We did not counterbalance the order of the non-stressful tasks (Video 1 and 2) and the stressful tasks (Job and IQ) for two reasons. First, the effect of elevated cortisol is long-lasting, and its carryover effects would be substantial. Second, we were restricted to measuring all blocks within the same time span due to the diurnal cortisol cycle and the day-to-day variety in the basal cortisol levels. To ensure that the results obtained were caused by stress rather than by task order, we conducted a control experiment with the same order of blocks, but without stress manipulation. During all blocks of EEG measurement, both in the original experiment and in the control experiment, the multi-feature paradigm, as described under "stimuli', was presented but not attended to.
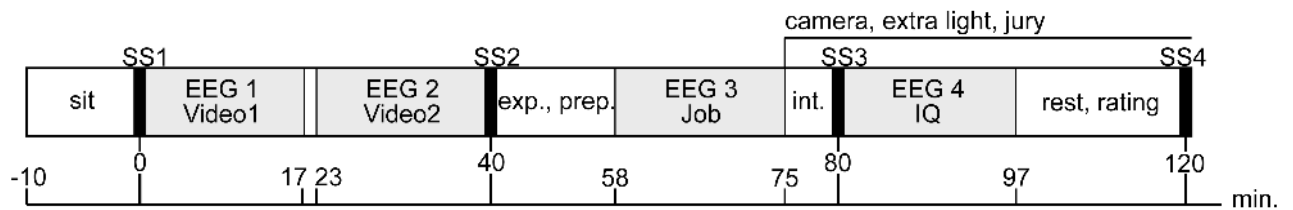
Fig. 2. Experimental design and time schedule. SS: saliva sample; exp., prep.: explanation of the task and preparation by the subjects; int.: job interview.

In Study II, there was no endogenous stress manipulation. Instead, the sensitivity of the HPA axis was measured with a challenge by exogenous low-dose dexamethasone, which tricks the HPA axis into thinking that the glucocorticoid levels are so high that a negative feedback mechanism is in order (via GR). Consequently, if the HPA axis is more sensitive to feedback than normal, then the glucocorticoid (cortisol) levels will be more suppressed than normal. Hearing thresholds were measured with and without the influence of dexamethasone, on different days at the same time of day.

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3.5 Stress assessment

The stress hormone cortisol is normally measured from blood or saliva. In this thesis, we opted for saliva assessment because this method is non-invasive, reliable, and provides a measure of the unbound fraction of cortisol. This free unbound fraction is the bioactive form that passes the blood-brain barrier and thereby affects brain regions (Marin et al., 2010).

In Study I (Fig. 2), saliva samples were taken prior to the EEG experiment (baseline), after the non-stressful Video EEG blocks (no stress), after Job (anticipation stress), and after IQ (stress and mental challenge). With the timing of the saliva sampling, the 10 to15 minute delay between blood cortisol and salivary cortisol was taken into account. There was also at least 40 min between consecutive samples, as cortisol levels usually peak around 30 min after the onset of the stressor. The participants were instructed to remain seated during the entire protocol in order not to contaminate the samples or the EEG recording with movement artefacts (for a review, see Mastorakos et al., 2005). In addition, prior to the baseline sample, the participants had been seated for at least 10 min. The participants had also been instructed not to smoke, sleep, exercise vigorously, brush their teeth, eat or drink anything but water during the hour prior to the experiment in order to avoid interference with the samples. The experiments took place in the afternoon to rule out individual differences in cortisol responses due to different stages of the circadian cortisol time course.

The samples were taken with Salivettes (Sarstedt Inc., Nümbrecht, Germany). Salivettes are cotton swabs placed in a plastic holder. The participants were asked to chew on the swab for 1 to 2 min. The samples were then stored at - 20 ºC until analysis.

In addition, subjective ratings of stressfulness were gathered. At the end of Study I, the participants rated the different phases in the test experience by means of the adjectives fatiguing, positively energizing, boring, challenging, relaxing, and stressful.

Salivettes were also used in Study II. The participants in this study also took samples at home for the assessment of basal cortisol on Days 1, 3, and 5 (Fig. 3). On each of these days, samples were taken on awakening, 30 min later, before lunch, before dinner, and before going to bed. One day of rest (day 4) was provided. Hearing tests were performed on Days 0 and 2. A dose of dexamethasone was taken at 23.00 o'clock on

Day 1. The following day, additional saliva samples were taken to assess the cortisol suppression every hour between 8.00 and 12.00.
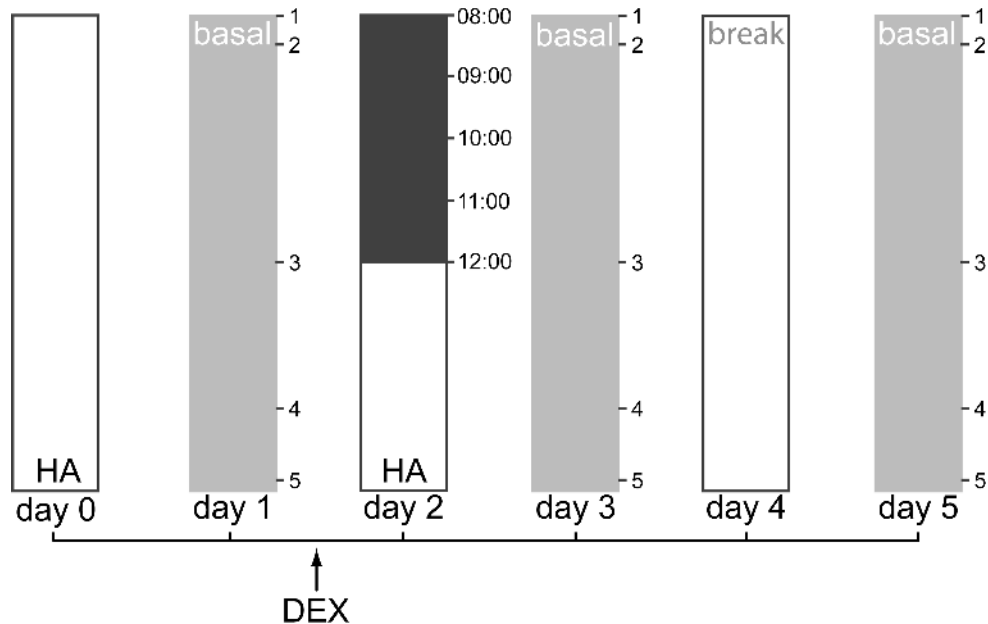
Fig. 3. Experimental procedure of Study II. Days 1, 3, and 5: basal cortisol assessment. Saliva samples were taken 1) after waking and before getting out of bed; 2) 30 min later; 3) before lunch; 4) before dinner; and 5) before going to bed. Dexamethasone (DEX) was administered on Day 1 at 23:00. On Day 2, samples were taken at the lab at 8:00, 9:00, 10:00, 11:00, and 12:00. On Day 4, no samples were taken. Hearing assessments (HA) were made on Day 0 (pre-DEX) and Day 2 (post-DEX) at the same time of day.

3.6 EEG recording

The EEG recordings in Study I were conducted at the EEG laboratory of the former Department of Psychology, Cognitive Brain Research Unit, University of Helsinki, with 128-electrode caps (Biosemi, Amsterdam, The Netherlands) with two additional electrodes, one on each mastoid. Facial electrodes were placed on the nose (reference in Study I), the canthi (horizontal electrooculogram [EOG] electrodes), and above and below the right eye (vertical EOG electrodes). Data were obtained with a 512-Hz sampling rate and were online bandpass filtered between 0.1 and 100 Hz. Electrode impedance was kept below 5 kΩ in both studies. The recording took place in an electrically shielded room, in which the participants were seated in a comfortable soft chair with head- and footrest.

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3.7 Data analysis

3.7.1 EEG analysis

The raw Biosemi data obtained in Study I were converted off-line to Neuroscan format (Compumedics-Neuroscan, Charlotte, NC, USA), and filtered between $1 - 30$ Hz with a 24-dB zero phase shift bandpass filter. The data were then divided into epochs (100 ms pre- to 500 ms post-stimulus onset) and the baseline corrected to the mean of the pre-stimulus interval. Epochs containing EEG and EOG signals exceeding $\pm$ *75* μV were rejected and omitted from further analysis. The responses to standard- and deviant stimuli epochs were averaged separately. Further analysis was then done using Matlab (The MathWorks, Natick, MA, USA), partly using routines from the EEGLAB toolbox (Delorme & Makeig, 2004) and custom-written functions. Missing channels in the original recording due to impedance changes during the experiment were replaced with the average of the closest adjacent electrodes.

Measures of instantaneous global field power, consisting of activity of all electrode leads irrespective of their location, were obtained in addition to regular ERPs. In Study I, the root-mean-square (RMS) was used.

The MMN (Study I) was obtained by subtracting the averaged responses to standards from the averaged responses to deviants. The latency of the most negative grand-average MMN peak – between 100 and 200 ms in each channel separately – was used as the centre of the peak detection time window (50 ms) in all participants. The same was done for the most positive grand-average peak for the RMS values. Similarly, the N1/P2 peaks of standards and deviants were determined in a 100-200 ms range.

3.7.2 Cortisol analysis

Saliva samples of Study I were analyzed in the Finnish Institute of Occupational Health (Helsinki, Finland). The cortisol content of the samples was measured with a competition-based luminescence immunoassay kit (IBL Inc., Hamburg, Germany). Both the intra- and interassay coefficients of variation of the cortisol assay were less than

10%, according to the manufacturer. Saliva samples of Study II were sent for analysis to the University of Trier (Germany). There, the samples were measured with a time-resolved fluorescence immunoassay. The inter-assay coefficient of variation was below 50%.

In Study II, the basal cortisol measurements were analyzed as the area beneath the curve and as diurnal cortisol values. Diurnal values were determined as the mean cortisol level at each time of day across the three days of basal cortisol assessment. In addition, the cortisol suppression as a result of the dexamethasone administration was determined as % suppression (100 - ((AUC2 post-DEX/mean basal AUC) *100), where AUC2 post-DEX is the area beneath the curve of the post-DEX day, cut off at 226 min, and the mean basal AUC is the mean area underneath the curve of the basal cortisol assessment of Day 1 and Day 5 (averaged), also cut off at 226 min.

3.7.3 Statistical analysis

In all the studies, Bonferroni or Holm-Bonferroni corrections were applied to multiple comparisons. Prior to selecting the statistical tests, all variables were tested for normal distribution. The statistical tests used in the different studies are mentioned in the results section.

4 Results

4.1 What is the effect of acute stress on pre-attentive sensory memory? (Study I)

The protocol to inducing acute stress designed for Study I did indeed elevate levels of the stress hormone cortisol in most participants (57.7% responders). The protocol was also rated stressful by the participants. However, the cortisol levels did not correlate with the subjective stress ratings (Table 3).

Acute psychosocial stress attenuates the MMN response (deviants - standards) to changes in duration, but not to changes in frequency, intensity, location, or the occurrence of a gap (Fig. 4). In addition, the responses to duration deviants were attenuated as well, but only among participants who showed an elevation in the stress hormone cortisol during the stress manipulation. Decreased adaptation (shown by a larger ERP amplitude) of responses to the standards was also observed in the stressful condition. However, this effect was not related to cortisol levels.

Table 3. Most relevant statistical tests and their significance (Study I)

Comparison	Test	Significance
Cortisol levels vs. subjective stress ratings	Pearson correlation	$p > .05$
RMS peaks MMN vs. baseline	paired t-tests	all $p < .05$
Effect of conditions (Video, Job, IQ), features, stimulus type (deviants, standards), and electrode location on MMN RMS values	repeated measures ANOVA	all $p < .05$
Duration deviants responders vs. non-responders	independent t-test	$p < .05$
Original study vs. control study	paired t-test	$p < .05$
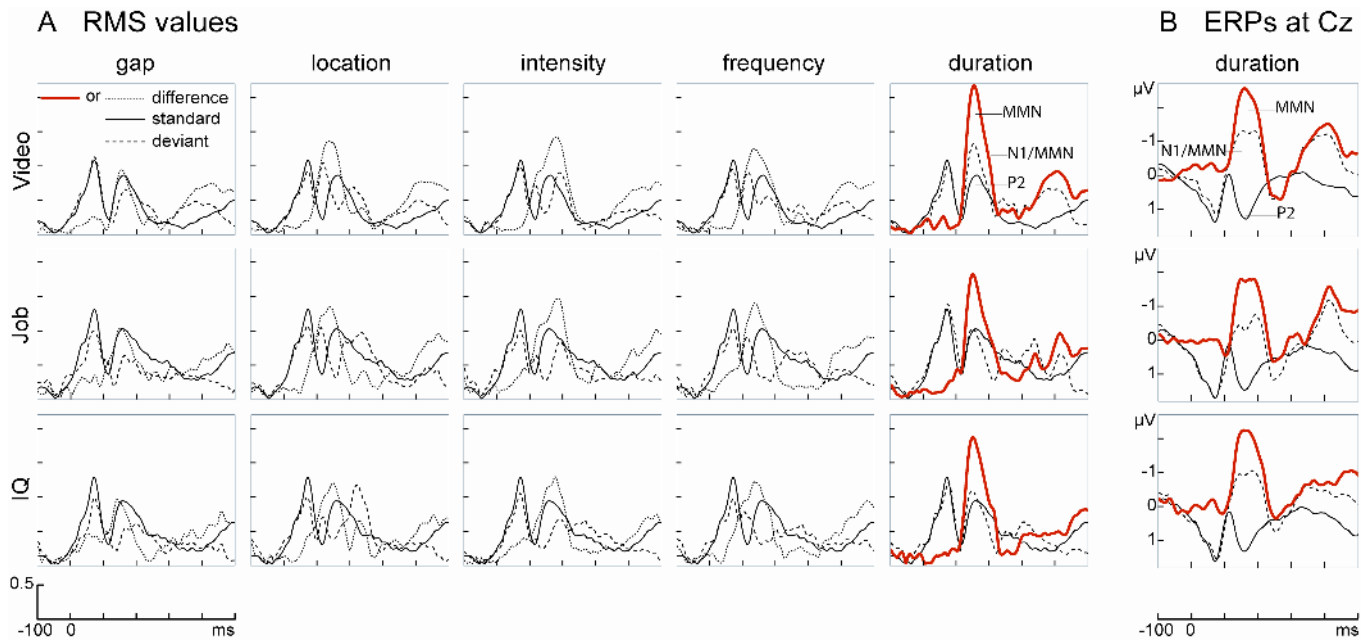
Fig. 4. A) RMS values of the responses to standards, deviants, and the MMN difference waves (deviant - standard) of all deviating sound features in the different EEG conditions Video (low stress, low mental workload), Job (high stress, low mental workload), and IQ (high stress, high mental workload). B) Standard and deviant ERPs and MMN difference wave responses to the duration deviant at the vertex electrode Cz. Only the responses to the duration deviant were affected during acute stress. For the duration change, difference waves are marked in red.

An additional goal of Study I was to disentangle the true acute stress from high mental workload, as these two phenomena are often intertwined in other studies. Both stressful conditions (Job and IQ) induced reduction in the MMN amplitude to duration changes as opposed to the non-stressful conditions (Video 1 and 2). However, the topography of these MMN attenuations was different for Job and IQ, which differed in mental workload. The attenuation of the duration MMN amplitude was strongest at right frontal sites when mental workload was high (IQ) and at the vertex when mental workload was low (Job, Fig. 5). To rule out the possibility that these effects could be attributed to an order effect, an additional control experiment was conducted. It confirmed the previous findings, namely that the effects of mental workload are distinct from the effects of acute stress.
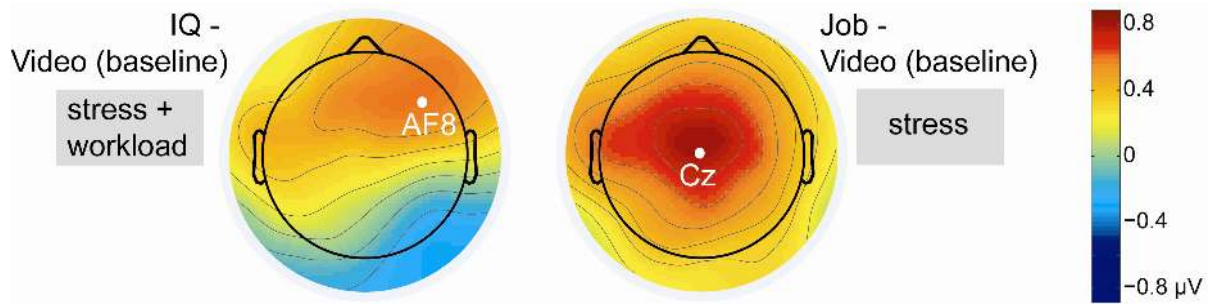
Fig. 5. Scalp distribution of the differences in duration-MMN between IQ and Video (IQ–Video), maximum at right frontal AF8, and between Job and Video (Job–Video), maximum at vertex Cz, at the MMN peak latency of 155 ms after stimulus onset (Study I).

4.2 What is the effect of chronic stress (tinnitus) on the HPA axis sensitivity? (Study II)

The diurnal cortisol analyses showed a normal circadian pattern in both tinnitus and control groups (Study II, Table 4). However, there was a difference between the groups in the other measure of basal cortisol in which the areas below the curve of all three days of basal cortisol assessment were compared. Day 3 of basal cortisol assessment followed the post-dexamethasone day (Day 2). Cortisol levels of this day were lower than the other days of basal assessment among tinnitus patients, but not among the healthy controls. In our view, this suggests that dexamethasone had a longer-lasting effect among tinnitus patients than among healthy controls. This effect was in accordance with a stronger rate of cortisol suppression in these patients after administration of this drug (Fig. 6).

Study II also explored the effect of cortisol levels on hearing and discomfort thresholds in tinnitus patients and healthy controls. Whereas in both groups hearing thresholds remained unaltered after dexamethasone administration, tinnitus patients exhibited a lower discomfort threshold. This means that they were more sensitive to louder sounds when cortisol levels when suppressed due to the drug.
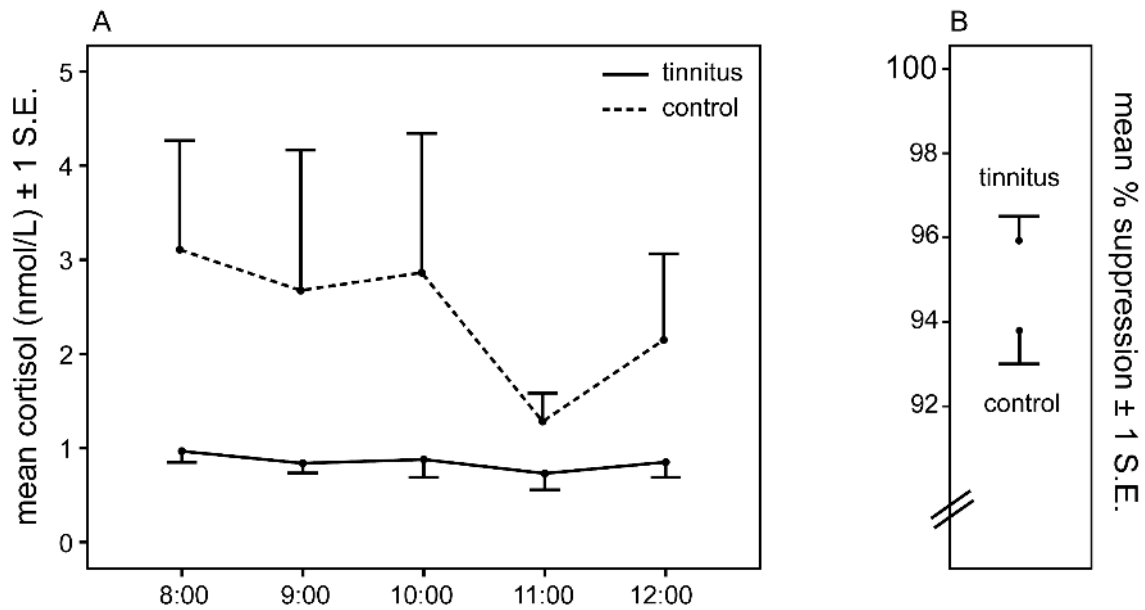
Fig. 6. A) Mean cortisol on Day 2 (post-dexamethasone); and B) Percent suppression of cortisol after dexamethasone administration for tinnitus and healthy controls. In addition to exhibiting longer-lasting effect of the drug, tinnitus patients also showed a stronger suppression of cortisol in their response. Note the very small variation in cortisol levels among tinnitus patients.

Table 4. Most relevant statistical tests and their significance (Study II)

Comparison	Test	Significance
Diurnal patterns, by group (tinnitus, control) and time of day	ANOVA	$p > .05$
AUC basal cortisol, by days and group	ANOVA	$p = .020$
% suppression, by group	independent t-test	both $p \leq .05$
Hearing threshold, by pre- and post-DEX and group	ANOVA	$p > .05$
Discomfort thresholds, by pre- and post-DEX and group	ANOVA	$p > .05$
Discomfort thresholds, by pre- and post-DEX among tinnitus patients	paired t-test	$p = .029$

Note. DEX: Dexamethasone, AUC: Area under the curve. P-values in ANOVA are given for the combined effects as described under Comparison.

4.3 Is the positive boost the opposite of debilitating MPA? (Study III)

From a principal component analysis with the MPA-related factors (Table 2, '16-MPA factors'), questionnaire items of five variables were statistically identified and used in the further analysis: (1) debilitating MPA (cognitive and somatic MPA manifestations), (2) *boost*, (3) self-oriented perfectionism, (4) performance confidence, and (5) avoidance. By contrast, the three remaining variables, acting as coping, fear of negative evaluation, and post-event processing, were excluded from further analysis due to a lack of coherence in the analysis. Questionnaire items referring to *boost* loaded on very distinct components from the items of the established general MPA questionnaire PAQ (Table 5).

Even though there were slightly more musicians with the combinations high PAQ score with low *boost* score and vice versa than expected by chance, high or low scores on both variables were very common. Of the 320 participants, 66 had both PAQ and *boost* scores over the cumulative 50% and, on the other end, 54 participants had both scores below the cumulative 50%. Furthermore, *boost* did not contribute to the regression model of general MPA or vice versa (Fig. 7).

The PAQ measures MPA as it is commonly assessed, with a strong overlap with social phobia and no emphasis on the actual debilitating aspects of MPA. Even though the general MPA and the *boost* seemed to be two rather distinct features, debilitating MPA and *boost* were clearly related. Debilitating MPA contributed mildly to the model of *boost* (*Beta*: -0.20, $p < .05$), and *boost* contributed to the model of debilitating MPA in musicians whose MPA did not have a strong negative impact on their careers (*Beta*: -0.18, $p < .05$).

The different MPA types were also differently related to perceived pressure and support. Perceived pressure played an important role in debilitating MPA (with low and high career impact by MPA, respectively $.05 < p < 1.0$ and $p < .05$) and general MPA (PAQ, $p < .0005$). In the *boost* regression model, not pressure ($p > .05$), but perceived support ($p < .05$) contributed to the model.

Table 5. Most relevant statistical tests and their significance (Study III)

Comparison	Test	Significance
Distinctness *boost* vs. PAQ	PCA Varimax rotation, Kaizer normalization	n = 293, KMO = .92, Bartlett's Test of Sphericity $p < .0005$. Cum. % of the listed components = 60.87%.
Distinctness MPA factors	PCA Varimax rotation, Kaizer normalization	n = 270, KMO = .86, Bartlett's Test of Sphericity $p < .0005$. Cum. % of the listed components = 59.92%.
Distribution > cum. 50% PAQ and *boost* scores	Chi square	$p < .05$
PAQ regression model	linear regression	R = 76.5%, adjusted R^2 = 55.8%
boost regression model	linear regression	R = 50.8%, adjusted R^2 = 21.1%
Debilitating MPA regression model (low impact)	linear regression	R= 71.2%, adjusted R^2 = 45.1%
Debilitating MPA regression model (high impact)	linear regression	R= 74.7%, adjusted R^2 = 46.6%

Note. PCA: Principal component analysis. Cum.: cumulative. Components in PCA were determined based on eigenvalues (> 1.0) and Scree plot.

4.4 Which factors contribute to the experience of MPA in musicians? (Study III)

Musicians were divided into two groups according to the impact of MPA on their careers. 34.4% reported a strong MPA impact on their careers. In musicians whose careers had been strongly affected by MPA, debilitating MPA was connected with more health-related factors, such as alcohol consumption, sleep quality, and psychological distress, than their colleagues ($p < .05$ or $.05 < p < 1.0$, Fig. 7). The contribution of pressure in these affected musicians was also double as high as in their less affected colleagues. Besides perceived pressure, the MPA in less affected musicians still seemed under the influence of performance confidence and *boost* (both $p < .05$).
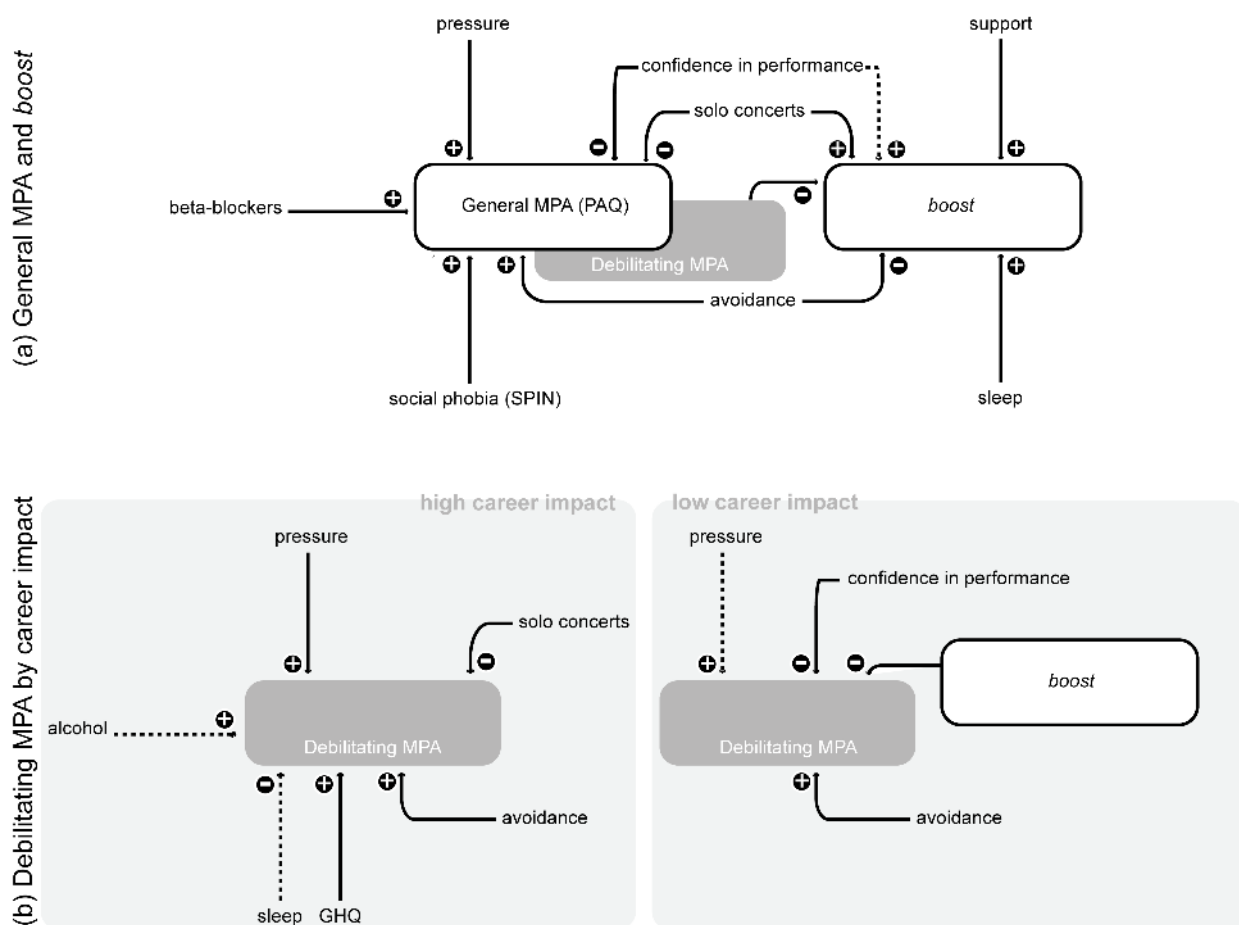
Fig. 7. (a) General MPA and *Boost*. Schematic overview of the regression models for General MPA (PAQ) and *Boost*. General MPA does not contribute to the *boost* model or vice versa. Debilitating MPA, on the other hand, does contribute to the *boost* model. General MPA as it is commonly assessed seems more related to social phobia. In addition, general and debilitating MPA are related to perceived pressure, whereas the *boost* is related to perceived support. When debilitating MPA was added to the regression model of boost, Performance confidence changed from significant to marginal contributor.

(b) Debilitating MPA by career impact. Schematic overview of the regression models for Debilitating MPA for musicians reporting high and low impact of MPA on their careers/studies. When debilitating MPA has a low career impact, this type of MPA is still related to performance confidence and *boost*. When the career impact is high, this type of MPA is more related to aspects of mental distress as measured by the GHQ, sleep quality, and alcohol consumption.

Arrows indicate predictor to dependent variable (without any causal relationship). + positive coefficient, - negative coefficient, **....** marginal predictor. MPA: music performance anxiety; PAQ: performance anxiety questionnaire; SPIN: social phobia inventory; GHQ: general health questionnaire.

4.5 Does the type of identification with one's musical instrument affect MPA and general professional well-being? (Study IV)

The majority of musicians felt 'so united with my instrument/voice that there is no difference between us' (United Group, 51.3%). The remaining musicians felt 'that it's really me as a person in front of the audience rather than my instrument/voice' (Person Group, 27.8%), 'protected/hiding behind my instrument' (Hiding Group, 10.9%), 'that my instrument is an obstacle to overcome between me and the audience' (Obstacle Group, 2.2%), or had no reply or more than 1 choice (7.8%). The United Group exhibited the most advantageous characteristics, whereas the Obstacle Group exhibited the most debilitating characteristics (Table 6).

Table 6. Characteristics of two extreme identification groups (Study IV)

United Group	Obstacle Group
older, more experienced	high MPA-impact on career/study
more professionals	higher level of stress during concerts
lower score in social phobia (SPIN)	lower performance confidence
lower score in debilitating MPA (study III)	strong avoidance
lower score in general MPA (PAQ)	higher scores in mental distress (GHQ)
higher score in *boost* (Study III)	'playing music is not as fun as it used to be'
less perceived pressure	
perform mostly for the audience	

Note. The reported variables showed statistical differences (p < .05) in chi square tests (differences between identification groups in distribution of gender, student/professional, smokers, instrumentalists/vocalists, education- and performance genre, MPA evolution, use of beta-blockers, musicians who never tried anything to combat MPA, and musicians expressing the need for more interventions), Kruskal-Wallis tests (differences between identification groups other than those tested by Chi square tests) or post-hoc Mann-Whitney U tests (if Kruskal-Wallis tests were significant). Correction for multiple comparisons was applied.

5 Discussion

The studies included in this thesis investigated the effects of acute and chronic stress and music performance anxiety on multi-faceted aspects related to sound perception, musical performance, and occupational well-being in musicians, as well the biological repercussions such as increased sensitivity of the hypothalamic-pituitary-adrenal (HPA) axis.

Pre-attentive sensory memory allows detection of a sudden change in the sound environment without the involvement of attention to evaluate its relevance and to decide unconsciously whether attention should be drawn to the change or not. In extreme situations, this process could even be crucial for an organism's integrity. It is therefore a logical step to study how acute stress affects this process. Indeed, the results of this thesis show that acute stress attenuates sensory memory functions. The results also show that chronic stress exposure, as a common co-morbidity in tinnitus, might be a predisposing factor for tinnitus or even alter the sensitivity of the HPA axis itself.

Musicians often express an accepting or even romantic attitude to both physical and mental suffering, including music performance anxiety (MPA), as part of the artistic experience. However, in accordance with previous studies, the findings in this research point out the debilitating relevance of MPA for a musical career. In contrast to most previous studies, attention was also paid to performance *boost*, which can enhance performance. Furthermore, possible anchor points for MPA treatment were identified, such as perceived pressure and support, and the type of identification with one's instrument. In the following sections, three topics will be discussed in more detail: (1) Acute and chronic stress: HPA axis and sensory memory, (2) Acute and chronic stress: Hearing and discomfort thresholds, and (3) MPA and the influence of identification with one's instrument.

5.1 Acute and chronic stress: HPA axis and sensory memory

In Study I, an acute stressor was applied to healthy students. The reactivity of the HPA axis was then observed by cortisol elevations, as well as its effect on sensory memory

for different sound features. In Study II, tinnitus was seen as an example of a condition with chronic stress, and the two types of glucocorticoid receptors regulating the HPA axis (GR and MR) were studied.

The majority of the participants in Study I responded with elevated cortisol levels to the stressor as a sign of an activated HPA axis. The designed stress paradigm adapted to EEG was thus considered successful. It was expected that not all would respond with such elevation, taking into account the inter-individual variability in the HPA axis reactivity due to genetic factors (Wüst et al., 2004; Uhart et al., 2004), gender and age, (Kirschbaum et al., 1999; Kudielka & Kirschbaum, 2005; Kudielka et al., 2004), blood glucose levels (Gonzalez-Bono et al., 2002), atopic disease (Buske-Kirschbaum et al., 1997; 2003), and different psychological aspects (Gordis et al., 2006; Roy, 2004; Gaab et al., 2003). In a previous study in which tinnitus patients were submitted to acute psychosocial stress, a delayed and blunted cortisol response was found among these patients (Hébert & Lupien, 2007). In addition, basal cortisol levels in the absence of an acute stressor were found to be no different in this overall group of patients than among age-matched controls (Hébert et al., 2004). These findings already suggested a differential affliction of the GR (HPA axis feedback) and MR (basal cortisol). Study II indeed confirmed this surmise. Dexamethasone (binding to GR) administration caused stronger cortisol suppression in tinnitus patients than in healthy controls, meaning that the HPA axis in these patients was much more sensitive to negative feedback. In addition to a stronger effect, the effect was also longer-lasting in these patients as there was a carry-over effect onto the following day. In contrast, basal cortisol measures between patients and controls were not different, meaning that the MR system seems to be unaffected in tinnitus patients.

Even though all participants in Study I rated the stressor as stressful, not all showed elevated cortisol levels. Differences in ERPs were found between responders and non-responders, which therefore could not be due to the subjective stress experience only, but also reflected the effects on substances such as cortisol on the generation of ERPs. Only among responders were responses to duration deviants attenuated. Responses to frequently repeated standards, on the other hand, were not related to cortisol response. It is therefore possible that feature-unspecific sound processing (i.e., general sound processing, as opposed to processing of feature-specific sound changes) is modulated by

other mechanisms of stress reaction. Future studies might focus on disentanglement of these two mechanisms and investigate the effects of acute stress on the adaptation of repeated sounds.

Only the sensory memory for sound duration was affected by acute stress in Study I, leaving the memory for location, frequency, intensity, and the occurrence of a gap unaffected. In accordance with our findings, Ermutlu et al. (2005) found MMN responses to frequency changes unaffected by acute (cold) stress. By contrast, Born et al. (1987) found these frequency MMN responses to be affected by the administration of hydrocortisone (artificial cortisol). Because Born et al. (1987) most likely induced extremely high cortisol levels, it is possible that sensory memory of frequency would also be affected in our study if the cortisol levels had been higher than those we observed. In any case, the fact remains that sensory memory of duration seems to be more sensitive to acute stress than the other sound features. At least part of the explanation could be found in the separate processing of the different sound features throughout the auditory system. Frequency processing probably has the most robust coding mechanism of all features with its hardwired tonotopic projections from the spiral ganglion in the cochlea throughout ascending pathways to the auditory cortex. Not as much is known about duration processing. However, it is likely to be less hardwired and thus more sensitive to manipulations such as acute stress. Neurons in low-level (primary) auditory cortex always show sharp frequency tuning (Morel et al., 1993; Rauschecker et al., 1995). There is, however, little evidence in humans that low-level neurons are selective for sound duration. It is thus possible that sound duration discrimination relies more on higher-level processing than frequency discrimination. High-level processes may be more susceptible to the influences of stress than lower-level processes. In addition, in certain clinical populations with chronically elevated cortisol levels, of which schizophrenia provides the most extensive MMN literature, the MMN responses to duration changes also seems to be more affected than the responses to frequency changes (Umbricht & Krljes, 2005).

Our results also showed that stress with low mental workload affected the duration-MMN in a different topography (max at vertex) than did stress combined with high mental workload (max at right frontal sites). These findings therefore call for caution in the interpretation of previous studies in which tasks with a high mental workload were

used as acute stressors (Dedovic et al., 2005; Wang et al., 2005). And also vice versa: studies on mental workload might need to take into account the effects of acute stress, which can be unintentionally provoked (e.g. Kramer et al., 1995).

5.2 Acute and chronic stress: Hearing and discomfort thresholds

In addition to the study of HPA axis sensitivity among tinnitus patients in Study II, the effect of cortisol suppression (after dexamethasone administration) in controls and the combined effect of chronic stress and cortisol suppression in tinnitus patients were explored. When cortisol levels were suppressed, the discomfort threshold lowered (tolerance decreased), despite unaltered hearing thresholds. This effect was more pronounced among tinnitus patients. Given the stronger sensitivity of these patients to cortisol manipulation, this finding supports a direct effect of glucocorticoid action on the inner ear cells among others, as GR have been found in abundance in the human inner ear (Rarey & Curtis, 1996). This is also in accordance with previous findings in individuals with cortisol depletion, in which restoring cortisol levels increased discomfort thresholds (Henkin & Daly, 1968).

The finding of increased sensitivity to sounds among tinnitus patients is an important one, as it is present in 80% of these patients (Dauman & Bouscau-Faure, 2005). Discomfort thresholds are also believed to predict tinnitus prevalence and severity in the general population (Hébert et al., in press). A next step in the understanding of this problem could be the examination of the dose response relationship between cortisol manipulations and changes in hearing and discomfort thresholds.

5.3 MPA and the influence of identification with one's instrument

Results regarding music performance anxiety in Studies III and IV were obtained with a large questionnaire survey. The findings showed that music performance anxiety as it is

commonly assessed (general MPA: PAQ, without emphasis on the debilitating aspects) is not likely to be just at the other end of the spectrum of *boost,* as is often predicted by existing U-shape models (Wilson, 2002; Papageorgi et al., 2007). This conclusion is based on the distribution of musicians with both scores higher or lower than the cumulative 50%. In addition, items of the PAQ and *boost* loaded on very different components. And finally, neither PAQ nor *boost* scores contributed to each other's regression models. A possible explanation for general MPA and *boost* as distinct features comes from Tomaka et al. (1993). General MPA could be more related to threat, whereas *boost* could be more related to challenge. Interpolating the statements of Tomaka et al. (1993), musicians who perceive a task as a challenge rather than a threat could demonstrate more physiological changes leading to energy mobilization. The *boost* could be a manifestation of these physiological changes.

A second finding in Study III was that debilitating MPA was connected with more health-related factors in musicians whose careers had been strongly affected by MPA than their colleagues'. The type of analysis did not permit any conclusion about the causal relationship between debilitating MPA and health. However, prolonged exposure to stress deteriorates health through various pathways. Then again, poor health and health behaviours may contribute to an inability to cope with stressors, creating a vicious circle. In contrast to musicians with high career impact from MPA, among musicians in whom MPA was less detrimental to their career, confidence in their own performance and *boost* influenced MPA. The importance of performance confidence in relation to MPA was already pointed out by Wolfe (1989), who found that the most and the least anxious performers differed in their awareness of poor preparation and poor performance. One could speculate that factors such as confidence and *boost* can be regulating factors as long as the debilitation of MPA has not gone too far.

The contribution of pressure to debilitating MPA was double as strong as in musicians with high career impact compared to those with low career impact. The results cannot exclude the possibility that this group indeed experiences more pressure in their careers or studies than the low impact group. If so, the perceived pressure could be a more accessible anchor point not only in the treatment of debilitating MPA, but also in the protection of a vulnerable musical career of a musician suffering from strongly debilitating MPA. In fact, perceived pressure was related to both debilitating

and general MPA. Perceived support, on the other hand, was related to *boost*. Combining these findings, targeting perceived pressure and support might be important anchor points in the treatment of MPA or in attempts to elevate *boost*.

Musicians often report that seeing their instrument as part of themselves is a sign of a high level of professional well-being. The results of Study IV confirmed that this identification type was indeed related to professional well-being in terms of MPA and other performance-related factors. If musicians felt as one with their instruments, they tended to have lower scores on social phobia, general MPA (PAQ), debilitating MPA, and perceived pressure. In addition, they reported more *boost* and performed more for the audience than other musicians did. A possible explanation for this phenomenon comes from the research on *flow* (Nijs et al., in press; for the *flow* concept, see Csíkszentmihályi, 1990). Characteristics of this state include intense and focused concentration on the task, loss of awareness of oneself as a social actor, a sense of control, and the experience of the task as rewarding in itself (Csíkszentmihályi & Nakamura, 2002). It is also associated with physiological effects, such as changes in heart period, blood pressure, heart rate variability, and respiratory depth (de Manzano et al., 2010). In order to reach the state of *flow*, one should perceive the engaging activity as a just-manageable challenge to one's skills and have clear proximal goals and immediate unambiguous feedback (Csíkszentmihályi & Nakamura, 2002).

All the previously mentioned characteristics of musicians who felt united with their instrument might contribute to the pleasurable experience of *flow*, reinforcing the positive experience of musical performance. By contrast, when a musician is hindered by something such as debilitating MPA, which could draw attention away from the musical experience by attention lapses or somatic stress features such as heavy sweating, the state of *flow* is not likely to be attained, and the music might not be played as intended. Consequently, the gap between the musician and the instrument remains.

The least favourable of the identification type options was to see the instrument as an obstacle to overcome. This identification type was related, among other things, to lower performance confidence, stronger avoidance, and higher stressfulness ratings during concerts. Low performance confidence would easily jeopardize the *flow* experience. Whereas anticipation stress is somewhat normal in musicians with a healthy dose of MPA, stress *during* the performance could be a sign of another phenomenon. If the

challenge seems too big to tackle, the musician might start opting more and more for avoiding musical performances. In addition to perceived stress and support, identification with the instrument might thus also be a point of attention for musicians striving for well-being.

In this thesis, the flow experience has been used as the reasoning behind the differences in professional well-being between the musicians with different identification types. This rather narrow approach is due to a lack of research of this topic in other fields, such as in cognitive neuroscience. However, recent research with relevance in the current context has made progress in the understanding of the use of tools. The use of tools is believed to alter either the representation of the space around us or the body schema. The space around us can be perceived differently by the use of a tool, as a region in distant space can selectively be re-coded as being near (McCormack et al., 2011). A body schema is a representation of the body that the brain uses to plan and execute an action, constantly updated by proprioceptive information. This representation is considered highly plastic, with the capacity to incorporate objects (Cardinali et al., 2012). Even more, tools are often specifically designed and conceived to overcome human body limitations and thus to modify the body configuration itself (Cardinali et al., 2012). When future studies have tackled the neural basis of this specific tool use, further research might also look into possible differences in brain activity between musicians in unity with their instrument and those who feel that their instrument is an obstacle to overcome.

5.4 Conclusions

First, the HPA axis was challenged with an acute stressor in healthy students. The resulting cortisol elevation was related to attenuated sensory memory for sound duration, which suggests that cortisol interferes with the pre-attentive mechanisms of the sensory memory formation. During acute stress, there was also a reduced adaptation to repeated sounds, which was not related to cortisol levels. This suggests that other stress-related mechanisms are involved in feature-unspecific processing. The effects of acute stress had a different topography than the effects of mental workload. This calls

for caution in the interpretation of studies that examine the isolated effects of mental workload or acute stress while unintentionally inducing the other as well.

Second, the HPA axis was also challenged in tinnitus patients and healthy controls by administration of low dose-dexamethasone. Whereas tinnitus patients showed no difference in basal cortisol levels (MR-mediated) compared with controls, they did show a longer lasting and elevated feedback sensitivity of the HPA axis (GR-mediated) to dexamethasone. In addition, tinnitus patients became more sensitive to sound loudness with suppressed cortisol levels. Long-term stress exposure and its deleterious effects therefore constitute an important predisposing factor or a significant consequence of tinnitus.

Tinnitus has been shown to be an appropriate model for chronic stress. However, as in all afflictions associated with chronic stress, disturbed sleep and depression do often co-occur in tinnitus patients, thus limiting the deduction possibilities of the results of studies concerning tinnitus and chronic stress. In addition, tinnitus patients commonly suffer from hearing loss, a condition of which the relationship to HPA axis functioning has not been fully explored.

Third, a broad survey on music performance anxiety showed that debilitating music performance anxiety and *boost* are not likely to be merely opposite extremes of the more general music performance anxiety. When debilitating music performance anxiety had a strong impact on a musical career, it was related to aspects of health and seemed no longer under the influence of confidence or *boost,* which was the case with low impact on a career.

All negative forms of music performance anxiety were related to perceived pressure, whereas *boost* was related to perceived support. In addition, the way musicians identified themselves with their instruments also seemed related to professional well-being and music performance anxiety. Musicians who perceived their instrument as a part of themselves showed advantageous characteristics for performance and well-being. Perceived pressure and support, as well as identification with the instrument, might thus be valuable anchor points in the treatment of anxiety and striving for higher states of professional well-being in musicians. Furthermore, these findings might contribute to occupational well-being in other fields of work as well, in which public

performances might prevent employers from achieving the status they would otherwise deserve, leading to social, socio-economic, and occupational disadvantages.

To summarize, the studies in this thesis demonstrate that acute and chronic stress, as well as MPA, affect several cognitive and endocrine processes, as well as behavioural and even occupational functions. From the scientific viewpoint, this evidence might guide one to reinterpret some of the previous findings in the stress literature in which the effects of mental workload and acute stress have been intermixed. Moreover, the four studies are also informative regarding research on clinical populations in which the functioning of the HPA axis is altered. Finally, from the educational and occupational viewpoint, the findings in this thesis could be of relevance to the treatment of performance anxiety in musicians and in other professions requiring public appearances.

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