The investigation of musicians' physiological and psychological responses to performance stress

Lisa Aufegger

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Abstract

Stress in music performance shows an intrinsic relationship with changes in cardiovascular functioning and emotions, yet to date, studies analysing these stress indicators are few and far between. The overarching aim of this thesis is therefore to investigate performance stress through the lens of both self-reported anxiety and physical stress signatures in heart rate variability. For rigour, this is achieved through a close examination of the relationship between stress and structural complexity of heart rate variability in response to different conditions musicians underwent: (1) a low- and high-stress performance and (2) a simulated performance environment. In my thesis I approached the problem in a comprehensive way and investigated five Studies. Studies 1 and 2 (Chapters 3 and 4) employ new heart rate variability methods to analyse physical stress. Study 3 (Chapter 5) compares heart rate variability responses before and during a performance in a simulated and a real-life performance environment; Study 4 (Chapter 6) qualitatively addresses further enhancements related to simulated performance environments. Study 5 (Chapter 7) examines heart rate variability responses to simulated performance feedback of different emotional valence. Results provide conclusive evidence that musicians performing in high-stress conditions display lower levels of structural complexity in the heart rate variability (signature of high stress), in particular prior to the performance, and a statistically significant elevation of subjective anxiety. The findings show that both simulated and real performance scenarios create similar physical and emotional responses. Interviews with musicians reveal the benefits of simulations in combination with complementary training methods. More immediate follow-up research may focus on heart rate variability responses to other training strategies, such as Alexander Technique and physical exercise; use a greater selection of standardised self-assessments; and evaluate musicians experiencing severe performance stress, for which this thesis has paved the way.

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Dedication

This thesis is dedicated to my parents.

Words cannot express how grateful I am and always will be.

‘A true artist never portrays to please, but to show.’

CHRISTIAN MORGENSTERN, Levels

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1 Introduction

The experience of performance stress depends upon many individual factors. For some, the amount of time spent on practice or the difficulty of the piece can be controlled, whereas for others, factors including the type of situation are subject to great variability, effectively making each performance a unique experience. The perception of these experiences can be experienced positively (i.e., eustress) or negatively (i.e., distress), with mental, physical and behavioural symptoms sometimes occurring hours, days or weeks before an actual performance. These symptoms can include a pounding chest, excessive sweating, or problems focussing attention on a given task. If these problems are reinforced through a lack of sufficient coping strategies or due to a particularly vulnerable predisposition (e.g., a high level of trait anxiety), a musician is likely to experience debilitating performance stress, potentially leading to a phenomenon labelled as music performance anxiety.

Over the past four decades, research has particularly focused on the psychological responses to performance stress, such as music performance anxiety, and has largely ignored the physiological component, including changes in a musician's cardiovascular activity. Unlike music performance anxiety, which is usually described as the feeling of worry and uncertainty prior to a particular performance (and which may involve the experience of physiological symptoms and the deployment of various behavioural strategies), performance stress is primarily focused on the body's reaction in its environment to the demands placed on it in order to meet the challenges of a particular kind of performance. To clarify the differences and similarities between stress, performance stress and music performance anxiety, the following sections provide an overview of each phenomenon and its causes. Then, I discuss the development of my own professional background and how I became interested in studying performance stress.

The concept of stress

Classically, theories of stress have been divided into two main categories (Derogatis & Helen, 1993): *response-oriented theories* and *interactional or transactional theories*.

The *response-oriented theories* define the response to the environment as the main causal factor involved in the experience of stress. As such, it is the pattern and amplitude of the physical and mental response that has been used to classify the intensity and degree of stress perception. This has, for instance, been observed in the degree to which the response manifests itself in the physiological system, such as through the release of the stress hormone cortisol and the likelihood of an increase in skin reactions, muscle tension and pain sensitivity (see Table 1.1).

The first major contributions to understanding stress and its physiological manifestations from a response-oriented perspective arose from Cannon (1929) and Selye (1950), who both closely examined the relationship between a stressor and a stress response in relation to the *sympathetic nervous system* (SNS) as well as the *adrenal glands' activity*.

To clarify, the SNS is part of the complex neuronal network whose basis is the central nervous system (CNS). The CNS consists of the brain and the spinal cord, and has three main functions: the input of sensory information, the integration of information and the motor output. These functions are carried out by the transmission of impulses and information by means of afferent and efferent nerve cells and synapses that are connected throughout the body. In other words, once information (e.g., sensory input) from the internal/external environment has reached and been processed by the brain, impulses are sent back through the spinal cord to the muscles and glands, generating a specific output. The CNS is further supported by the peripheral nervous system (PNS), a vast network of mainly sensory receptors which functions as an additional source of information. The PNS itself is divided into the somatic nervous system and the autonomic nervous system (ANS). While the somatic nervous system provides information to and from the joints, skeletal muscles, bones and skin, the ANS involuntarily controls the internal organs, such as the cardiovascular, respiratory or endocrinological system. The ANS is divided into two subsystems, the sympathetic (SNS) and the parasympathetic system (PNS), with the first activating the metabolic output and the latter slowing it down (Sarafino, 1996).

Both the SNS and PNS have a distinctive structure; the SNS contains fibres that are mainly located at the large ganglia located near the spinal cord, with both the preganglionic SNS neurons and postganglionic neurons traveling to the targeted organs (e.g., the heart), leading to cross-communication and co-activation facilitated by the neurotransmitter norepinephrine. In contrast, in the PNS, the '. . . preganglionic fibres exit from the brain-stem and sacral segments of the spinal cord and synapse with postganglionic fibers close to the target organs without passing through common ganglia' (Levenson, 2014, p. 101). Due to the fact that neurotransmission throughout the PNS occurs through the release of acetylcholine, the circulating norepinephrine does not lead to distorted activation of the PNS (Levenson, 2014).

In an attempt at defining and understanding stress, Cannon identified four main components of a stress response, which he considered to fall under the umbrella of the *fight-or-flight response* (and the activation of the SNS): (1) The body requires a stable and regulated state to function flexibly, which means that (2) an interruption of this stability by a specific stressor automatically involves changes in our physiological mechanisms (in order to regain control). (3) These physiological mechanisms are diverse and work simultaneously as well as separately, and (4) are a result of organised autonomy. As such, the *fight-or-flight response* enables us to focus so we can quickly respond to the situation through an increased metabolic output (Sarafino, 1996).

In contrast, the *adrenal glands' activity* is part of the endocrinological system and is responsible for distributing hormones such as cortisol or adrenalin into the blood stream. Based on the activation of the CNS and the hippocampus, corticotrophin-releasing hormones (CRH) and arginine vasopressin (AVP) are sent out from the hypothalamus to the anterior pituitary gland, secreting adrenocorticotropic hormones (ACTH). Reaching the zona fasciculata of the adrenal glands, the ACTH activates the *outer adrenal cortex* and the *inner medulla*, with the former producing glucocorticoids, such as cortisol, and the latter generating catecholamines, including epinephrine or norepinephrine. Both are in charge of diffusing oxygen, glucose and lipids (i.e., energy carriers) to the muscles and the brain in order to reduce the sensation of pain, increase anti-inflammatory activity and ensure adequate immune functioning.

Selye was particularly interested in the interplay between stress and endocrinological responses, and based on his work, he created a model for understanding stress which is called the *General Adaptation Syndrome*. In this model, he considers stress responses to be comprised of three main stages: (1) an alarm reaction (comparable to Cannon's fight-or-flight response), (2) a stage of resistance, involving increased physiological arousal to adapt towards the stressor, and (3) a stage of exhaustion, resulting from stress exposure over a long period of time and thus weakening the physiological system. If not prevented (e.g., by sufficient coping strategies), a consistently high level of arousal leads to a phase of exhaustion, fatigue and the increased likelihood of developing disorders such as depression and anxiety.

In contrast, *interactional or transactional theories* define stress through an emphasis on the organism as a mediator between the stimulus (and the stimulating characteristics of the environment) and the patterns of the stress responses that they trigger. Thus, interactional theories have been developed in consideration of the fact that response-oriented theories may be too simplistic to fully grasp the impact of stress since they do not consider the importance of the person, which has been found to form the basis of great variations within and between the different responses to stress among individuals. Transactional theorists therefore not only consider the person that is impacted by the relationship between the environment and the stress response, but also the cognitive, perceptual and physiological characteristics of the person himself/herself. In particular, these theories highlight the dynamic interplay of the reciprocal interactions between the individual (including cognition, perception and physiology) on the one hand and the environment on the other, with feedback pathways conducting constant updates amongst these components in order to achieve homeostasis. As a consequence, such theorists believe that the experience of stress is a product of the assessment of the situation (the properties of the stimulus), the individual's personal capability to handle the distressing event and the particular physical and mental response patterns involved.

A well-known model that relies upon the assumption of the interactional or transactional theories is the *transactional model* developed by Lazarus (1993). The transactional model highlights the importance of the cognitive appraisal of the stress stimuli (Lazarus & Abramovitz, 2004; Lazarus, 1993). In doing so, cognitive appraisal is characterised by three main features: (1) associative processing, which consists of a quick and automatic recall of past experiences and memories; (2) processing which takes longer, yet is more flexible and encompasses conscious thinking; and (3) the monitoring of the overall incoming appraisal information, involving the evaluation of the situation in terms of motivational relevance and congruence, the coping potential and whether stress is caused by the individual himself/herself or whether it is imposed by another person. Based on these three appraisal methods, it has been proposed that stress is neither a simple product of circumstances nor exclusively dependent upon personal characteristics; rather, it has been characterised as a '... relationship between the person and the environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her well-being' (Lazarus & Folkman, 1984, p. 19). Therefore, restoration of the physical and psychological resources involved happens through the application of effective coping strategies.

Table 1.1: Physiological responses to stress (Lehmann et al., 2007, p. 147).

Adaptive bodily function	*Sensation felt*
Heart beats vigorously to increase oxygen supply to muscles	Pounding chest
Glands in the skin secrete perspiration to lower body temperature	Excessive sweating, wet palms
Lungs and bronchial airways open to supply more oxygen	Shortness of breath
Saliva flow decreases	Dry mouth, lump in the throat
Digestive system is inhibited as blood is diverted from stomach to muscles	'Butterflies' in the stomach, nausea
Pupils dilate to sharpen distance vision	Blurring and focusing problems

Music performance anxiety *versus* performance stress

Music performance anxiety Someone who is interested in understanding the concept of music performance anxiety[1] should be advised to read Diana Kenny's seminal book *The Psy-*

[1]Other expressions to explain music performance anxiety are *stage fright*, *performance anxiety* or *music performer's stress syndrome* (Fehm & Schmidt, 2006). Often used interchangeably (Papageorgi, Hallam, & Welch,

chology of Music Performance Anxiety (Kenny, 2009). Kenny illuminates music performance anxiety in practically all of its guises, and critically examines its causes, symptoms and treatments, as well as their meaning and implications for practising musicians.

By first laying out psychological frameworks embedded in a short historical overview, Kenny creates an understanding of the development of general and specific theories of music performance anxiety. She discusses nomothetic and idiographic approaches, Descartes' and Freud's theories of body and mind, Darwin's and Canton's assumption of survival, and the importance of biology and the environment. She also explains how anxiety can become problematic, or in the worst case, pathological. She then refers to the classifications, defining features, commonalities and differences of anxiety disorders, using the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) to discuss '... whether people suffer from a unique condition known as performance anxiety or whether their performance anxiety is a manifestation of another underlying anxiety disorder or other psychopathology' (Kenny, 2011, p. 34).[2] After setting out the groundwork, she defines music performance anxiety. Kenny points out that, while many researchers have sought to provide new insights into phenomena related to music performance anxiety, they have typically lacked a coherent and consistent definition of the underlying concept, '... the first and essential step in its analysis and eventual understanding' (Kenny, 2011, p. 47). For a concise definition, we can turn to one of Kenny's earlier publications:

> Music performance anxiety is the experience of marked and persistent anxious apprehension related to music performance, which has arisen through specific

2007), each expression has to be noted with differences in its quality and according to their level of arousal. Steptoe (2001) for instance distinguish stage fright and musical performance anxiety in terms of the evaluative nature of the situation. To put this into context, performance anxiety does not only appear on stage rather than in various of settings (e.g., one to one lesson or rehearsal). Further the experience of anxiety due to upcoming performances may build up days before, whereas the term *fright* is associated with an unexpected appearance of fear which does not necessarily imply impaired performance.

[2]The threshold between commonly and benign experiences of anxiety and the sensation of anxiety that causes clinical relevant interference with one's life is defined in the International Statistical Classification of Disease and Related Health Problems (ICD) or the more commonly known Diagnostic and Statistical Manual of Mental Disorders (DSM: Bögels et al., 2010). Both are internationally used guidelines and cover a wide range of medical and psychological health condition, defined through a 5-axes-system. This clinically relevant system includes clinical disorders (Axis I), underlying personality disorders (Axis II), acute medical conditions (Axis III), psychosocial and environmental factors (Axis IV), and global assessment of functioning for children under the age of 18 (Axis V).

> anxiety-conditioning experiences. It is manifested through combinations of affective, cognitive, somatic and behavioural symptoms and may occur in a range of performance settings, but is usually more severe in settings involving high ego investment and evaluative threats. It may be focal (i.e., focused only on music performance) or occur comorbidity with other anxiety disorders, in particular social phobia. It affects musicians throughout their lifetime and is at least partially independent of years of training, practice and level of musical accomplishment. It may or may not impair the quality of the music performance (Kenny, 2009, p. 433).

Kenny has arrived at this definition by unravelling overlapping theoretical approaches. The above is predicated upon Barlow's emotion-based theory, a triple set of susceptibilities which is responsible for developing anxiety/mood disorders, emphasising genetic contributions, and general and specific (early-) life experiences as sufficient conditions to produce MPA (Barlow, 2000). To put this into context, the triple set of vulnerabilities emphasises genetic contributions, as well as general/specific (early-) life experiences as the main indicators for developing anxiety (disorders). Genetic vulnerabilities can be seen as traits, such as high levels of neuroticism or introversion, strongly determining and predicting specific reactions across different conditions (Spielberger, Gorsuch, & Lushene, 1970). General life experiences may be experienced by the lack of secure attachments in early childhood, while specific vulnerabilities encompass negative somatic sensations during an evaluative process. All of them reinforce the feeling of uncontrollability and unpredictability in handling these situations successfully, likely to develop a variety of clinically, temporally sustainable anxiety disorders, including social anxiety, panic disorder, or obsessive-compulsive disorder (Barlow, 2000).

These conceptualisations are used to describe the epidemiology and measurability of music performance anxiety and function as a precursor for Kenny's own model. She outlines the advantages and disadvantages of test batteries, introducing her Music Performance Anxiety Inventory. This particular questionnaire stems from Barlow's theory, including among other factors uncontrollability, self- and third-party evaluation, physiological arousal and memory bias (Kenny & Osborne, 2006). It has been adapted across a wide range of age groups, offering a '. . . careful assessment of each musician's anxiety profile [. . .] so that targeted treatment for each of the concerns can be addressed in therapy' (Kenny, 2011, p. 107). Furthermore, she refers readers to empirical work in which her questionnaire has been shown to achieve sufficient reliability (Kenny, 2005). Kenny's model of music performance anxiety focuses on how it develops, as well as how anxiety-related problems persist and desist, comprehensively synthesising extant social context, behavioural, cognitive and emotion-based learning processes.

After surveying theoretical perspectives that explain the causes of music performance anxiety, Kenny turns her attention to common forms of therapy. Here, she not only lists cognitive/behavioural, psychoanalytic, emotion/performance-based and multimodal approaches, but also scrutinises non-Western and other alternative methods including mindfulness-based stress reduction, yoga, music therapy, biofeedback and the Alexander Technique, as well the effect of self-administered substances such as alcohol, caffeine and cannabis. In doing so, she concludes that, while a variety of possible treatments have become available over the past 30 years, '. . . empirical validation is [still] required before treatments can be recommended' (Kenny, 2011, p. 231). Kenny also illustrates severe manifestations of MPA and draws together the theoretical and clinical perspectives reviewed earlier in the book through a series of vivid personal accounts of musicians' music performance anxiety experiences, punctuated by preventive and pedagogical advice. She gives the reader a sense of what it is like to suffer from music performance anxiety, the implications it has on one's life, the personal histories that are predictive of certain outcomes and how different individuals are able to address their fears. This interweaving of scientific research and personal narratives is what makes Kenny's book so compelling, and it gives musicians who suffer from music performance anxiety, as well as scientists, educators and interested others, the possibility of shared insight.

Finally, she highlights lingering questions and problems that should be addressed in future research. This includes the lack of studies into long-term treatment and the prevalence of often short-term or symptom-focused therapies, which in her words show '... statistical differences before and after treatment, but ... might not be clinically significant' (Kenny, 2011, p. 167). She points to the need for more replication of research findings, acknowledges that there are individual responses to different therapies, but also exposes the problems of ecological validity and highlights the recent progress of psychodynamically-oriented therapies. As a consequence, she not only focuses on adults and their performance anxiety-related symptoms but takes care to emphasise that age-specific and exposure-related music performance anxiety, particularly in childhood, must be investigated further.

In summary, music performance anxiety is an expression not everyone is willing to speak out loud if they suffer from having somatic, cognitive and behavioural vulnerability caused through negative experiences in performances. However, it has an impact on a multiplicity of musicians independent of their age, sex, experience or hours of practice. It is a psychological phenomena, which is characterised through symptoms such as increased heart rate, sweating, dry mouth, negative thoughts and misattributions (Osborne & Kenny, 2008). It creates stress responses (for more details, see section 'Performance stress'), which makes a performance—independent of the domain (e.g., sport, music or just public speaking)—very challenging, if not impossible (Goode, 2004). Estimates are that 2% of the US population are suffering from performance anxiety (Powell, 2004), where comorbidity (one third) is often the case. Furthermore, 10-15% of those affected with additional anxiety disorders, have also experienced episodes of moderate to severe depression (Kessler, DuPont, Berglund, & Wittchen, 1999). Great musicians as Vladimir Horowitz and Sergei Rachmaninoff had suffered from debilitating performance anxiety, affecting their perceived quality of performances their whole lives through. Reasons for experiencing performance anxiety may be the pressure of becoming a great artist, the financial challenges (most performers are not in the enviable position to have contracts lasting more then one month or even worse to get paid per hour) and the ambitious expectations of the audience to deliver a great performance. All those aspects can lead to negative thoughts, provide behavioural inhibitions and causes physiological disturbances (Lehrer, 1987). In sum, performance anxiety is a phenomenon, which affects a wide range of different musicians (from solo to orchestral musicians), with some of them even likely to quit their career due to performance anxiety (Wesner, Noyes, & Davis, 1990).

Performance stress In the last two decades, studies have put increased interest in studying music performance anxiety and its causes, yet little has been done in the field of music psychology (or performance science) with regards to the experience of performance stress. Unlike music performance anxiety, which is usually described as the feeling of worry and uncertainty prior to a particular performance (and which may involve the experience of physiological symptoms and recruitment of various behavioural strategies), performance stress is primarily focused on the body's reaction (and the environment) to the demands placed on it in order to meet any challenge to balance produced by any kind of performance. In particular, performance stress is determined by a specific stressor, its interpretation and processing, and followed by a stress response through the activation of specific areas in the central nervous system. The stressor (in this case performing) is an aversive physiological and/or psychological event that is caused by internal or external demands that exceeds one's resources to cope with these demands successfully. The stressor of performing is interpreted and processed either automatically, or it may incorporate higher cognitive processes, containing a detailed evaluation in terms of motivational relevance and congruence, future expectancy and whether the situation is self- or other-imposed (Compas et al., 2014; Scherer, 2009). While it is important to acknowledge that the experience of music performance anxiety is an aspect of the experience of performance stress, this thesis aims to break new ground by describing and evaluating a specific response to performance stress that has not received much attention in performance science, namely the changes in heart rate variability (alongside the sensation of anxiety) to performance stress. The next sections therefore provide a detailed explanation of heart rate variability and anxiety, before discussing the impact of both through the lens of 'emotion-specific autonomic responses'. At the end of this section, I provide an overview about my personal background and explanation of my personal interest in studying performance stress.

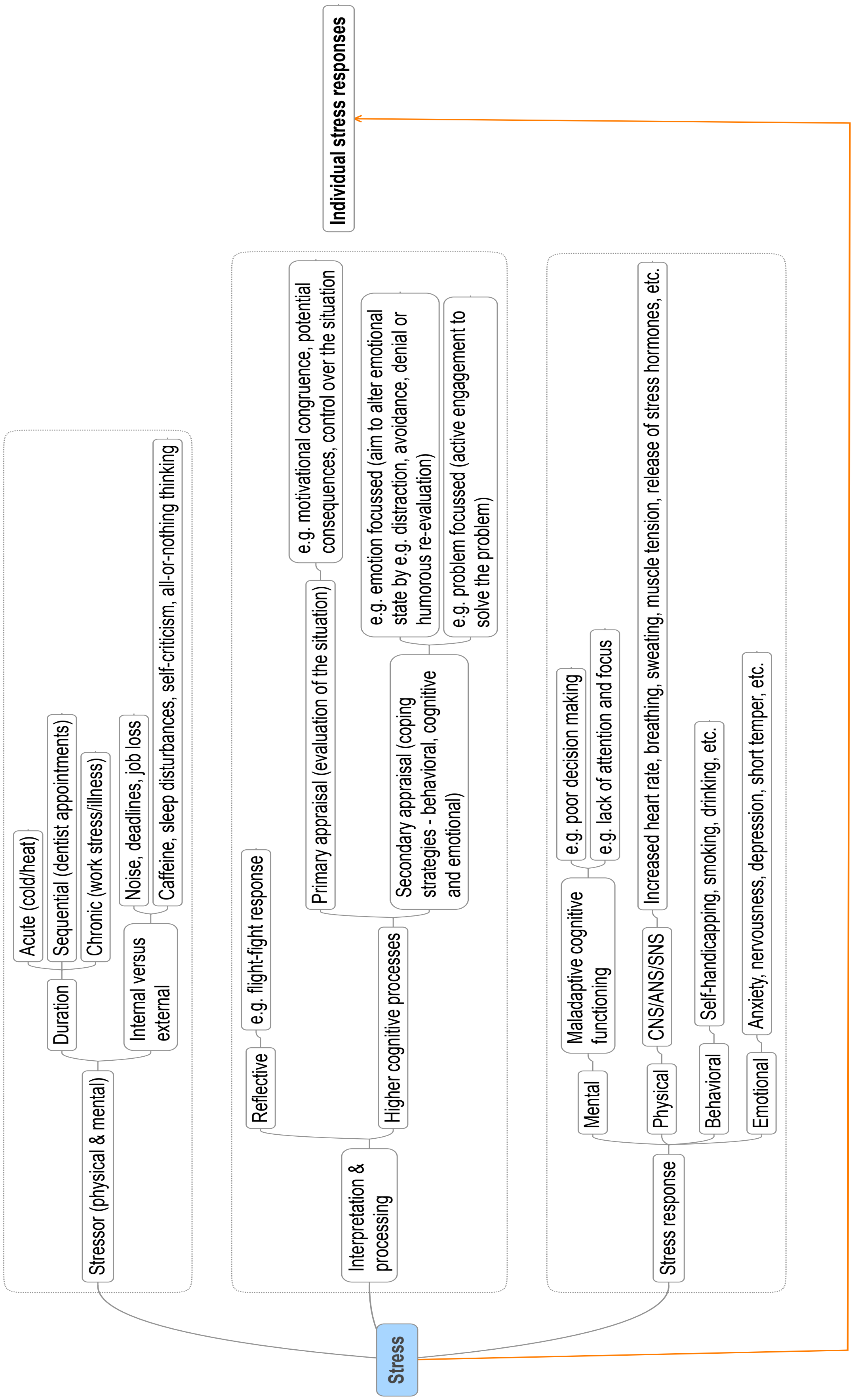

Figure 1.1: The concept of stress.

Heart rate variability An example of a physiological altered state due to stress is represented in the cardiovascular system. The cardiovascular system is built upon two essential components; a pump (e.g., heart) and a circulatory system (e.g., blood vessels), both of which are responsible for transport and passing specific nutrients to and from cells. In order to sustain adequate cardiovascular functioning, the heart has to transport blood with a certain stroke volume (i.e., amount of blood) and pressure gradient (i.e., blood pressure) upon the walls of blood vessels (Nichols, O'Rourke, & Vlachopoulos, 2011). As such, the human heart has two main targets; exchanging oxygenated/de-oxygenated blood (i.e., pulmonary circulation) and carrying the blood to all the organs and tissues (i.e., systemic circulation) by contracting and relaxing the chambers. This is done by the heart's two chambers at each side—with the upper chambers known as left and right atrium and the lower ones left and right ventricle, with four types of valves regulating the blood flow (Nichols et al., 2011):

- Tricuspid valve: Regulation of blood flow between right atrium and right ventricle;
- Pulmonary valve: Regulation of blood flow from right ventricle into pulmonary arteries (in order to collect oxygen from the lungs);
- Mitral valve: Regulates oxygenated blood flow (from lungs) from left atrium to left ventricle;
- Aortic valve: Controls flow of oxygenated blood from left ventricle into the aorta (in order to transport oxygenated blood and other nutrients into the rest of the body).

The regulation of the blood flow can be observed in the heart rate variability (Talbott, 2007). The heart rate variability is the fluctuation or beat-to-beat intervals of the heart rate and is triggered by the distribution of electrical impulses through the muscle cells of the heart (i.e., myocardium). Starting at the sino-atrial (SA) node, located at the top of the right atrium near the superior vena cava, the electrical impulses generate contractions of the atrium before reaching the atrioventricular node (AV). The AV is located at the bottom of the right atrium and transmits impulses through the His-Purkinje system of fibres, resulting in the contraction of the ventricles (Urbanowicz, Zebrowski, Baranowski, & Hollyst, 2007). Both the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) affect changes in the heart rate, which is observable within five beats (Sarafino, 1996 [response rate SNS: 15 s; PNS: 5 s]; Urbanowicz et al., 2007).

The heart rate variability is furthermore impacted by the respiratory system (Clifford, 2002). The main goal of the respiratory system can be described as an exchange of oxygen and carbon dioxide (i.e., O_2 and CO_2) between the organism and its environment. This is done by diffusing oxygen through the alveolar-capillary membrane into the lungs and transporting it through the organism's tissues for exchange (i.e., blood-air [or -gas] barrier). The mechanism of respiration can be characterised by four distinct patterns (Marieb, 2010): The *pulmonary ventilation* (i.e., breathing), which is the movement of air into and out of the lungs, the *external respiration* (i.e., gas exchange), the *gas transport* via the bloodstream, and the *internal respiration*, the exchange between blood and tissues, all of which are defined as the movement of *inspiration* and *expiration*. In other words, the respiration contains the act of inspiration (T_I), expiration (T_E), the pause between both, the volume during one breath (V_T), the total cycle duration (T_{TOT}) and the average respiration rate per minute.

While the T_I causes shortened heart rate variability, the T_E lengthens these intervals (Berntson & Cacioppo, 2004). Under relaxed conditions (i.e., baseline conditions), heart rate ranges between 60 and 80 beats per minute (bpm), yet can be substantially altered due to stress (>100 bpm), alongside a decreased T_E flow and an increased T_I flow (i.e., hyperventilation) and respiration rate (Clifford, 2002; Wientjes, 1992). This was for instance shown by Masaoka and Homma (2001), who addressed specific breathing patterns during anticipatory anxiety using electrical stimuli of 50 volts delivered to the forefinger. Anxiety was monitored by the standardized State and Trait Anxiety Inventory and a Visual Analogue Scales, anxiety sub scale (VAS: Aitken, 1969; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants were asked to wear a mask measuring the expired ventilation, the tidal volume, the respiratory frequency, the inspiration time and the expiration time. Compared to a 15 min baseline period, the anticipatory period led to a significantly increased sensation of state anxiety and an expired ventilation, while the times of inspiration and expiration was decreased. No other alterations were observed. However, when the sample was grouped into low- versus high-anxious participants, significant differences between groups were observed for the tidal volume, the breathing frequency, the expiration time, as well as the PET_{CO2}. Trait anxiety and breathing frequency were significantly positively correlated.

Overall, the respiratory patterns under stress are characterised through increased, relatively fast, shallow breathing, with a high mean of flow rate. As demands increase breathing patterns becomes less shallow and although the mean inspiratory flow rate is further augmented, there is no change in the rate of breathing (Wientjes, 1992).

The emotional experience of performance stress Stress may also cause maladaptive emotional experiences (Allen & Leary, 2010). Emotions have been broadly defined in terms of a '...distillation of an individual's perception of personally relevant environmental interactions, including not only challenges and threats but also the ability to respond to them' (Thayer & Lane, 2009, p. 85) and have to be considered as distinct from the concepts of mood and arousal. Emotions are affective conscious states and are structured in relation to a clear object. Moods are less intense than emotions, not directed towards a specific object and usually experienced for up to several hours (i.e., emotions are believed to be object-specific and shorter of duration). Arousal mainly reflects the activation of the ANS and may or may not involve an emotional component.

Although there is some debate about the exact definition of emotions, most researchers agree that emotions have four broad characteristics (Izard, 2007): (1) emotions trigger expressive behaviour derived from primitive evolutionary neurological substrates, expressed through common cross-cultural properties such as facial patterns; (2) the expression of emotions is dependent upon the perception of the stimuli, and does not necessarily incorporate any high-level appraisal or cognitive functioning; (3) basic emotions appear alongside an exclusive component of sensations (i.e., feelings), providing information for individual and social functioning; (4) emotions incorporate exclusive regulatory components that impact cognition and behaviour, and which function independently from homeostasis or natural physiological drives, such as thirst or hunger. Thus, emotions enable individuals to communicate a specific message (e.g., social support) through alterations in facial expressions, voice and body signals. While positive emotions such as joy or contentment facilitate attachment behaviour and the desire to discover, learn and attain new skills, negative emotions including anger, fear and sadness generate rapid and autonomic responses to distressing circumstances.

The valence and arousal of emotions in response to stress depend on how a stressor has been appraised. Cognitive appraisal involves the evaluation of individual goals, relevance, motives or needs. The main target of an emotion is to mobilise the biological and neurological processes that allow individuals to shift their performance and activity in a specific direction. These processes, which are partially governed by emotions, include goals, motivational priorities (desires, drives, needs, urges, intentions), information-gathering motivation, imposed conceptual frameworks, perceptual mechanisms, memory, attention, communication via emotional expression, behaviour, reflexes and learning (Mulligan & Scherer, 2012). For instance, prioritising goals, or putting goals in a hierarchical order, is an emotion-dependent activity and involves specialised processes that trigger certain behaviours. To put this into context, emotions should elicit or induce construals that allow for an appropriate decision to be made regarding a specific situation. This may include the retrieval of specific memories and perceptual processes as well as attention (Tooby & Cosmides, 2008). As such, emotions do not have clear boundaries and impact various physiological, mental and behavioural states. They contain a combination of processes that exhibit a great deal of variability. Consequently, as the experience of emotions emerges, it is created from underlying affective proportions. Indeed, most emotion-theorists see emotions as a product of the situational structure, or as described by Mulligan and Scherer (2012, p. 346): '. . . [an] emotion is never punctual and only some emotions endure without variation over time. Emotions typically unfold dynamically. Emotions have a beginning and an end, although their exact duration is difficult to specify. In consequence, emotion should be considered as an episode in the life of an individual.'

As for performance stress, research has shown that if the situation is motivationally relevant and incongruent, and no sufficient coping strategies are possessed, then a maladaptive emotional experience, such as performance anxiety, may accompany the stressor (Allen & Leary, 2010). The emotion of anxiety is defined by exaggerated rumination and worry. Rumination is symptom-focussed and has the negative side effect of causing failures in adaptive problem solving (Kenny, 2011). As such, individuals who ruminate are consistently reflecting on their problems without taking appropriate action (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Furthermore, anxiety strongly correlates with maladaptive functions such as self-criticism, negative self-concept[3] and attitudes, perfectionism, neuroticism, low task mastery and depression. For instance, musicians who experience an increased level of anxiety also tend to strive for flawlessness and focus on overly critical evaluations (Stoeber & Rambow, 2007). Both the striving for high performance standards and the concern about the outcome of the performance are correlated, which may lead to an unhealthy state of worry and rumination, as expressed by an exaggerated level of anxiety about an upcoming performance.

Generally, the feeling of anxiety that persists along with a higher tendency towards perfectionism has been interpreted as a multidimensional construct including three types of features: self-oriented, other-oriented and socially prescribed. For instance, studies such as the one conducted by Mor, Day, Flett, and Hewitt (1995) have revealed that musicians with a high degree of performance anxiety also present elevated levels of self-oriented perfectionism and socially prescribed perfectionism. Moreover, the presence or absence of a sense of personal control has been shown to be a strong moderator between perfectionism and anxiety, as well as perfectionism and goal satisfaction. Overall, individuals with a high level of anxiety and rumination exhibit interfering instrumental behaviour, including a lack of sufficient coping strategies to deal with the stress individuals experience before, during and after a performance.[4]

[3]Self-concept is defined as the view of oneself, formed out of a combination of environmental experiences, and reinforced or marked by some key factors such as *frames of reference* (Martens, Burton, Vealey, Bump, & Smith, 1990)—the standards someone uses to judge their own traits and accomplishments (e.g., social comparison); *causal attribution*—factors to which someone attributes failure or success (Skaalvik, 1997); *reflection from important others* (Rosenberg, Schooler, Schoenbach, & Rosenberg, 1995); master experience—the knowledge in a specific domain that is not only shaped by self-efficacy (Bandura, 1978), but also by one's self-concept (Skaalvik, 1997); and psychological centrality—the factor according to which self-esteem is seen as an important part of having an adequate self-concept (Rosenberg et al., 1995).

[4]Worry shares some of the same features with rumination; however, the experience of worry is future-

ANS and emotions Both the variability of one's heart rate and the emotions that are experienced under stress lead to an *emotion-specific autonomic response* (Cacioppo, Uchino, & Berntson, 1994; Kreibig, 2010; Quigley & Barrett, 2014; Stemmler, 2004). Such responses may be *coherent*, which means that the organisation and coordination of the emotions has an impact on different activities of the ANS and between the ANS and other response systems, such as facial expressions. They may also be *specific*, which means that each emotion triggers different patterns in the ANS (Levenson, 2014). Both characterisations are plausible, considering that the ANS has more than one role, performing as a regulator, activator, coordinator and communicator. For instance, the ANS acts as a regulator by maintaining homeostasis, which is represented by the maintenance of a body state in order to minimise internal damage and to maximise operational functioning (Levenson, 2014). If the ANS is understood as an activator, then it needs to be taken into consideration that the activity of the ANS is a result of short-term deviations that are not necessarily related to the function of homeostasis. Such side-activities of the ANS enable the body to cope with challenges and allocate resources where necessary without having an impact on the overall homeostasis. In contrast, the ANS as a coordinator helps to gather information in a not only afferent but also efferent fashion, and allows for the body to communicate any changes in the physical state between and from old to new brain circuits. Finally, the ANS also serves as a communicator, producing visible changes in our appearance and delivering a 'message' that can be perceived by our peers (e.g., facial expression: Levenson, 2014).

Considering all these different roles, functions and responsibilities of the ANS, the perception of stress may cause diffuse activation of the ANS, which involves a complex pattern of physiological communication that is affected within and between individuals, and which results in a high *noise-to-signal ratio*. Consequently, the objective assessment of distinctive emotion-specific autonomic responses is rather challenging.

In summary, the ANS is designed to cope with internal and external challenges, which, dur-

oriented and is not associated with thinking about past experiences (Kenny, 2011). Also, the ability to cope with everyday hassles and to prevent the manifestation of physical symptoms is strongly connected with high self-esteem and emotional support (DeLongis, Folkman, & Lazarus, 1988), which are directly connected to an individual's learning experiences.

ing the day, lead the body to experience a great variety of active ANS patterns, at one time occurring in isolation (e.g., change in heart rate and breathing) and at the other in combination with various physiological responses (e.g., changes in endocrinological responses and facial expression). In order to understand the interplay between the ANS and the emotional experience, it is important to determine when the activation of an ANS pattern is due to a specific emotional experience, or whether it is just a response caused by more banal homeostatic demands. For instance, changes in the pupillary diameter may be a result of different light conditions, changes in the airway tonus, or changes in cardiac contractility. Based on the huge variety of possible internal and external influences that can impact the ANS, it is important to acknowledge that any ANS activity may not only occur due to a specific emotion that is experienced (since it is possible to experience two or three emotions at the time), but also by daily demands and challenges that impact an individual's autonomic functioning (Levenson, 2014).

Although still under debate, the majority of researchers have considered emotion-specific autonomic response to consist of a top-down process, where the experience of emotions results in (distinctive) physiological response patterns. The impact that an emotion has on ANS activity has to date been assessed by three major systematic meta-reviews, with the main goal of differentiating between a variety of emotions and their underlying physiological dynamics.

Cacioppo, Berntson, Larsen, Poehlmann, and Ito (2000), for instance, reviewed 20 studies that analysed measures such as heart rate and respiration metrics to understand the physiological changes that arose due to emotion-inducing stimuli, including emotions such as happiness, disgust and fear. Their results showed that happiness caused greater heart rate acceleration than disgust and fear, and anger caused greater acceleration than happiness, but there was no difference between the corresponding rates for disgust and those among a control group. In contrast, less agreement was observed for the respiration metrics, including inspiration volume and respiration amplitude. Both were increased, decreased or unchanged during exposure to different emotional stimuli, suggesting different influences of the peripheral vascular function. Overall, the authors found that negative emotions trigger a greater response in the autonomous nervous activity compared to exposure to positive emotional stimuli. However, these results were subject to great variability.[5]

Stemmler (2004) investigated the effects of two basic emotions, fear and anger, on physiological responses including heart rate and respiration. He selected 15 studies assessing a minimum of two somato-visceral responses (e.g., heart rate and respiration) and calculated the magnitude of their effects (point-biserial correlation) for three conditions: (1) fear versus control; (2) anger versus control; and (3) fear versus anger. The results showed significant effects on heart rate and moderate effects on respiration when comparing fear versus control and anger versus control. In contrast, in studies comparing the exposure to stimuli such as fear versus anger, the results revealed more increased heart rates in fearful situations, a pattern that was also observed for the respiration rates. Thus, although fear and anger are theoretically assumed to share comparable features of valence and arousal, they exhibit distinct physiological specificity.

Last, Kreibig (2010) examined the impact of emotions on heart rate variability, in particular the frequency distributions of electrocardiographic signals. To this end, he selected 134 studies that explored emotional exposure to happiness, anxiety or sadness, and their impacts on physiological activity. Physiological measures mainly concentrated on cardiovascular and respiratory features, including frequency domain analysis (LF, HF, LF/HF), respiratory depth, tidal volume, duty cycle and respiratory variability (for more details, see Chapter 2). For the emotion of anxiety, the results showed an overall increase in the sympathetic nervous activity and a withdrawal of the vagal activity alongside faster and shallower breathing. In particular, Kreibig (2010) found an increase in heart rate, a decrease in heart rate variability and an increase in the LF power and the LF/HF ratio. With regards to respi-

[5]Based on the results, the authors developed a framework that aims to make sense of how emotional experiences might be shaped by (or shape) multiple (physiological) pathways. The model is referred to as the somato-visceral afference model (SAME: Cacioppo et al., 2000), a continuum on which one end represents emotional experiences as a result of distinct emotional somato-visceral patterns, and the other the perception of an emotion that is attributed to undifferentiated physiological arousal. Based on the assumption of continuous interplay between emotions and physiological responses, the model postulates that the perceptual process may produce a range of different emotions, as well as physiological responses that are related to more than one emotional experience. Moreover, the model assumes that the ANS is not only able to change the experience and the intensity of an emotion, but also that the sensation of emotions may be independent from the activity of the ANS, and thus not capable of discriminating between the emotions that are experienced.

ration, the results revealed an increase in the respiration rate, including a decreased T_I and T_E, and V_T. Interestingly, happiness-inducing stimuli triggered the same patterns, such as a decrease in vagal activity as well as increased respiratory activity; nevertheless, the findings revealed greater variability in comparison to exposure to the emotion of anxiety. Kreibig (2010, p. 411) emphasised a crucial observation within the psychophysiological stress research by stating:

> For progress in the understanding of the functional organisation of ANS activity in emotion, future researchers will have to closely scrutinise and, if possible, verify the specific type of emotion elicited as well as individual variations when analysing autonomic parameters that need to be selected such that they allow differentiation of the various activation components of the ANS. Only if the hypothesis of autonomic response organisation is properly tested, can valid inferences be drawn. It is hoped that this will pave the road [...] for a generative principle that can summarise and account for the varieties of emotion.

Fortunately, more recent models that enable us to '...closely scrutinise and, if possible, verify the specific type of emotion elicited' are provided by the Component Process Model (Scherer, 2009) and the *Biopsychosocial Model* (Blascovich, Mendes, Tomaka, Salomon, & Seery, 2003; Rith-Najarian, McLaughlin, Sheridan, & Nock, 2014; Seery, 2011; Turner, Jones, Sheffield, Barker, & Coffee, 2014), which consider the type of situation but also the way we appraise the situation as main drivers for emotion-specific autonomic response.

The Component Process Model considers the occurrence of specific emotional experiences to be the results of cognitive appraisals, which, in turn, lead to distinctive changes in the autonomic nervous system (e.g., heart rate variability).[6] In Scherer's model, appraisal involves:

[6]It should be noted that the experience of an emotion may also happen independently from the type of stressor (without cognitive appraisal), developed through (1) direct learning experiences and (2) indirect learning experiences, (3) 'biological preparedness' or (4) non-associative means (Nebel-Schwalm & Davis, 2013). Direct and indirect learning experiences encompass traditional learning approaches, such as classical conditioning or observational learning, while the biological component reinforces these conditions (e.g., individuals, for instance, who have a high level of trait anxiety may develop a quicker and stronger response to *fear-relevant* [e.g., spiders, snakes] versus *non-fear-relevant* [e.g., flowers] stimuli). In contrast, the non-associative pathway represents an alternative by questioning how much of an association is truly required to develop anxiety related symptoms, emphasising the unique impact of biological predispositions only.

(1) an old low-level neural circuit that functions automatically and which is genetically determined; (2) a schematic level, working fairly automatically by applying memory traces from social learning processes; (3) an association level, incorporating cortical brain areas, which may work unconsciously or be part of higher cognitive processes; and (4) a conceptual level, using propositional knowledge and effortful thinking. All four levels interact with one another, generating a multimodal framework that continuously updates itself.

The final outcome is ultimately determined by: (1) relevance; (2) implications; (3) coping potential; and (4) the estimation of consequences for the self-concept and social norms/values. In other words, any stressful event is assessed in terms of novelty, goal relevance and whether or not the situation is pleasant. The individual also assesses the probability of potential consequences, and the deviation from his/her own expectations. Moreover, the situation is evaluated in terms of self- and third-person responsibility, and whether the individual has the control as well as the power to change the situation (Table 1.2).

Table 1.2: Differences in physiological and psychological stress responses explained through the component process model (Scherer, 2009).

Individual differences	*Hardwired/constitutional automatic sensorimotor*	*Learned/dispositional Schematic unconscious*	*Transient/voluntary & Controlled Conscious*
Appraisal process	Genetic or cultural factors, brain circuit biases	Personal learning history (conditional perception tendencies, appraisal bias due to wishful thinking)	Momentarily dominant biases (hypothesis testing)
Motivational change	Reflexivity, impulsivity	Coping tendency, personality, dispositional reaction	Evaluation of adaptivity and success probability of action alternatives
Physiological responses	Vagal tone, temperament, stable-labile autonomic nervous system	Physiological responses schemata	Adopting physiological control stances

Furthermore, Scherer believes that each evaluation of a situation happens sequentially, where the individual undergoes a series of *stimulus evaluation checks*. In other words, the type and intensity of the emotion experienced is a result of the appraisal process based on a continuous execution of these checks. The first process of evaluation is the *novelty check*, where the individual examines the situation in terms of its familiarity. This is followed by an *intrinsic pleasantness check*, of which the outcome is based on learned associations and innate feature detection. The next checks are labelled as the *goal/need significance check* the *coping po-*

tential check and the *norm-self compatibility check*. The goal/need significance check assesses the extent to which the current situation is expected, urgent, or important to the satisfaction of the individual's personal goals. The coping potential check evaluates the degree of control over the situation, the potential to deal with the situation, the level of personal power over the situation, and the assessment of the options available for internal adjustment. Finally, the norm-self compatibility check evaluates and compares the intended actions with social and internal norms, the expectations of others and the standards of the self. Each check leads to changes in various subsystems that serve the emotion, such as physiology, expression, motivation, and feeling, thus, generating a pattern that defines the emotion. As such, the experience of emotions is fluid and a product of constant re-evaluation (Clore & Ortony, 2008), and depends on the characteristics of the situation, which then evolves into a particular pattern of stress response.

To apply this to the context of performance stress, if a situation is novel and unpleasant (e.g., an audition), a defence response is initiated, expressed through an increased heart rate, decreased salivation, increased muscle tension and shrinking posture. If the implications of this situation are harmless and do not cause negative consequences (e.g., a performance in front of your peers to rehearse her/his repertoire for an upcoming performance), but also less controllable and likely to change, a trophotropic shift occurs (Quigley & Barrett, 2014; Scherer, 2009). This includes the activation of several physiological components, such as the PNS, a variety of endocrinal glands, the anterior hypothalamus, portions of the limbic system and the frontal cortex. The opposite of trophotropic dominance is ergotropic dominance, exhibited through the SNS, the posterior hypothalamus, portions of the limbic system and the frontal cortex. Ergotropic dominance occurs when the situations are controllable, but the individual may not have the power to control them. This leads to fast and irregular respiration, a rapid increase in heart rate and systolic blood pressure and a decrease in diastolic blood pressure (Gellhorn, 1970).

Evidence to support the validity of the component process model has been found in a variety of studies that address the psychophysiological signatures of appraisal outcomes by adjusting the degree of pleasantness experienced and the possibility of goal achievement

(Johnstone et al., 2007; Johnstone, van Reekum, Hird, Kirsner, & Scherer, 2005). Related studies such as the one conducted by Johnstone et al. (2005) evaluated the impact of emotional changes in speech based on ANS activity by using a computer game to trigger emotional speech. The computer game was either conducive to or obstructive of the goal of winning, and was presented alongside a pleasant or unpleasant sound. A sample of 30 participants took part in the study, and their speech was analysed in terms of mean energy, fundamental-frequency level and utterance duration. The results revealed that the spectral density was associated with the manipulation of pleasantness, and that dynamics in pitch were dependent upon the interplay between the experience of pleasantness and goal conduciveness. However, the results also suggested that the changes in physiology were not only reflective of one particular emotion, which gives weight to the complexity of understanding emotional experiences through the lens of physiological responses.

In another study, Johnstone et al. (2007) monitored participants' changes in physiological markers such as skin conductance and changes in the frequency of their voices while performing a computer task with two levels of complexity, where participants either gained or lost points based on the outcomes of their performances. The results showed that the vocal changes mostly depended upon the interaction between gain, loss and interactivity. In particular, the rate at which the vocal cord was opened or closed was high with the experience of loss and increased difficulty (as opposed to the experience of loss and decreased difficulty). The results of the skin conductance analysis revealed higher sympathetic arousal in the loss situation than in the gain conditions, especially when the difficulty of the game was high. As a result, the authors concluded that changes in the SNS activity can be related to the emotional state based on the task's difficulty and can be detected by specific physiological markers, such as skin conductance and different rates in vocal folds. Moreover, the results implied that if the situation involves an increased risk of loss, the body mobilises its resources in order to actively deal with the situation, which is indicated by the increased SNS activity and the corresponding increased amplitude of skin conductance, as well as the opening and closing rates of the vocal cords.

The *Biopsychosocial Model* for understanding challenges and threats (Blascovich & Mendes, 2000; Blascovich et al., 2003; Blascovich, Seery, Mugridge, Norris, & Weisbuch, 2004) considers the distinctive biological factors that determine the physiological and psychological reactivity to stress, which are mainly determined by the perception of the situation as either a challenge or a threat (Seery, 2011). Similar to Scherer's model, it involves the concept of cognitive appraisal introduced by Lazarus and Folkman (1984), which mediates the effect between stress and stress response by evaluating a situation in terms of relevance and congruence, task engagement and coping potentials. However, the biological factor adds an additional component to the cognitive appraisal by allowing for the differentiation between positive and negative stress perception (challenge versus threat) and their distinctive physiological markers. In particular, these markers are determined by specific changes in the cardiovascular output (Seery, 2011; Turner et al., 2014).[7] For instance, sympatho-adreno-medullary activity has been associated with both threats and challenges, while activation of the hypothalamic-pituitary-adrenal axis—responsible for releasing the stress hormone cortisol—has been determined to be a response to threats only, tempering the sympatho-adreno-medullary activity and therefore resulting in higher total peripheral resistance and lower cardiac output (Seery, 2011). As such, the perception of a challenge has been connected with (1) an increase in cardiac output, and (2) a decrease in total peripheral resistance, while the perception of a threat has been associated with (1) a small increase or decrease in cardiac output, and (2) an increase in total peripheral resistance (Turner et al., 2014). Indeed, studies that have compared the effects of both the perception of a challenge and a threat of a particular situation have demonstrated that the perception of a challenge generates greater cardiac output as well as a more positive performance outcome, as opposed to the perception of a threat (Blascovich et al., 2004; Seery, Weisbuch, Hetenyi, & Blascovich, 2010).

To put this into the present context, Seery, Weisbuch, and Blascovich (2009) assessed the impact of motivated performance situations and was able to define four cardiovascular indexes that differentiate between *task engagement* and *challenge versus threat*. These were '...heart rate; pre-ejection period, an index of the left ventricle's contractile force; cardiac output,

[7] The physiological components have been incorporated into the model based on the assumption that self-reports are biased due to social desirability and may not be able to fully account for unconscious cognitive processing (LeDoux, 2003).

the amount of blood in liters pumped by the heart per minute; and total peripheral resistance, an index of net constriction versus dilation in the arterial system' (Seery et al., 2009, p. 309). Seery was also able to show that task engagement, when assumed to contain both perceptions of a challenge and a threat, was characterised by an increase in heart rate and a decrease in the pre-ejection period from baseline measurements, as well as more significant changes in both after inducing greater task engagement (see Figure 1.2).

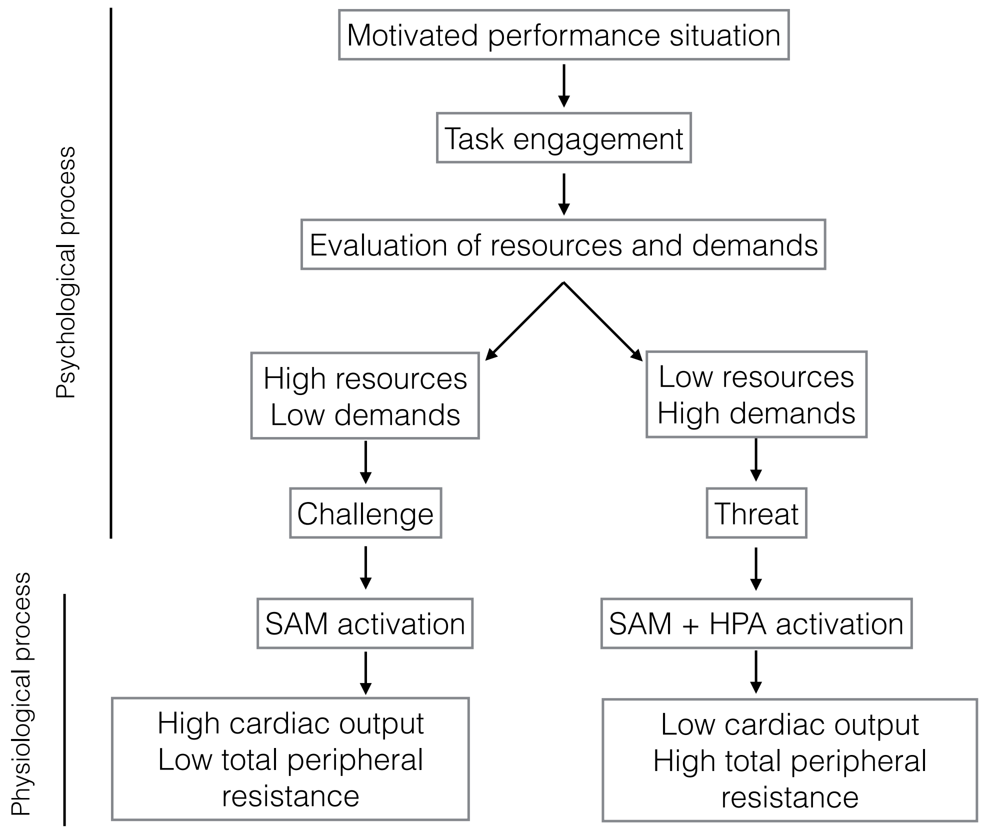

Figure 1.2: The Biopsychosocial Model.

Using the model to understand changes in the physiological markers associated with challenge and threat perception in sport science, Blascovich et al. (2004) evaluated the predictive validity between the induced motivational states in student athletes. They asked 27 baseball and softball team members to take part in a laboratory test, where each had to undergo a 5 min baseline measure and two 2 min performance tasks, first giving a speech about playing their sport, their quality of performance outcome (measured by the points achieved) and the performance expectation for the upcoming season (emotionally-loaded task). In another task, they had to give a speech about the general qualities a friend should have (emotionally non-loaded task). During both tasks, the authors monitored the athletes' impedance cardiographs, electrocardiography and blood pressure. The results showed that the physiological challenge/threat markers significantly predicted the athletes' perception of their performances (positive versus negative), as well as the anticipated performance outcomes for the subsequent season. In contrast, the outcome for the emotionally non-loaded task was different in that no relationship between perception and physiological markers was found. Based on these results Seery (2011, p. 536) stated that '. . . the cardiovascular responses associated with challenge/threat do not equate to challenge/threat itself, but instead represent an indirect measure of the underlying psychological state.'

Overall, the Biopsychosocial Model holds great promise for providing an in-depth understanding of the distinctive differences between positive and negative performance stress. Nevertheless, studies that support this theoretical framework for use in music psychology have yet to be conducted. Thus, while an extension of the Biopsychosocial Model to the domain of sport science has already been developed, future studies should evaluate the validity of the model for performance science and also consider the impact of musicians' self-focus when analysing the perception of challenges and threats prior to an upcoming performance.[8]

[8] The extension of the Biopsychosocial Model in sport science is known as the *Theory of Challenge and Threat States in Athletes (TCTSA)*, and acknowledges competition and facilitating or debilitating competitive anxiety in the field of sport psychology. It emphases the mediating effect of *resource appraisals*, such as self-efficacy, power of control, goal relevance and emotional state, to predict the effects of perceiving challenges or threats and performance outcomes.

1.1 Personal background and interest in performance stress

Personally, I was intrigued to know more about performance stress, in particular the stress evaluation over time and its affect on your body and mind. I am a musician myself and I remember vividly the performance that triggered my interest in studying performance science. It was a public performance, and after eight months of non-stop practice working on the same three pieces I was now standing in front of a packed hall waiting for my performance to begin. I had woken up early and even had my breakfast out ready to devour at 7am: A banana and smoothie containing blackberries and porridge. I had researched all the food to make sure it wouldn't make me more hyperactive or too alert. Arriving at university I got into my concert gear but did not put any shoes on as I had discovered that I preferred to play bare foot. As I waited for people to come in, I made sure that I did not speak to anyone at risk of them saying things that would make nervous. As I walked on stage I felt amazingly calm and began to play my unaccompanied Bach. 'WOW' I thought to myself I did it and it was good. Now the next one. Brahms. Feeling more and more confident as I played these phrases I started to move more freely and actually smiled. Then all of a sudden my fingers started doing the wrong thing—it was as if they had completely forgotten all the patterns I had worked tirelessly to learn. Oddly my bow kept moving and as a stumbled through the next few bars I found my way back eventually. All those hours of practice, all those tears memorising the music, all that extra preparation with what to wear and what to eat seemed wasted. I felt hugely disappointed but simply could not imagine how I would have done it differently. The next day I boarded a flight to America and spent the next eight hours digesting my performance. It was during that flight that I became determined to look at the physiological and psychological aspects of performance in order to understand more about performance stress, in particular pre-performance and its effect on body and mind.

I went on to study Psychology whilst carrying on playing the violin, I was then lucky enough to integrate the two subjects when I came to the Royal College of Music to start my PhD and later on my work as Graduate Teaching Assistant. I was fascinated about the musicians' experiences and I wanted to open up a conversation with musicians about their vulnerability towards performance stress, whether it was perceived as something debilitating or gave them the alertness needed to deliver a good performance. I just wanted to make sure that the subject of performance stress was not missed or ignored. The time as a Graduate Teaching Assistant allowed me to gain experience through the preparation of classes—and the assistance to the professor—but, most of all, to benefit from the close contact with the students. I hoped to learn as much from their doubts and questions as I was from the exchange of thoughts and ideas.

Being a psychologist with a musical background working with musicians, themselves interested in psychology, allowed for very productive and inspiring interactions and led to new perspectives for both the musicians and myself. As a psychology student, I got introduced to the topics of consciousness, learning strategies, categorisation of knowledge, as well as visual and auditory perception. Given my interest in auditive perception, I decided to develop a learning programme for my Masters thesis that would support non-musicians—as well as musicians—in achieving specific competencies in music perception; in my case, I focused on the perception of various brass- and woodwind instruments. The result showed that non-musicians were able to improve in a manner that is comparable not with experts but rather with semi-experts. Indeed, the finding suggested that regardless of society or educational level, everyone has the potential to learn to perceive music similarly than musicians do.

Studying at the Royal College of Music was a great opportunity to share my enthusiasm towards music psychology and get new insights from others (musicians and psychologists) in the field. It allowed for a flexible yet challenging learning environment, conducive to good results. When I started my PhD at Royal College of Music I attempted to get in contact with as many musicians from all musical backgrounds, performance interests and experiences as possible. It was then when I decided to focus on the impact of performance stress on physiological responses, but also to be keen on finding a way to give musicians an opportunity to practice and experience ‘performance stress’ whilst not being at risk of being judged. I was intrigued when I heard about the Centre for Performance Science building a state-of-the-art simulation training for musicians and I was keen to get involved and collect my data around it. Having developed my own training programme for non-musicians during my Masters, I perceived this as an ideal challenge to combine music and technology further.

The aim of this simulation was to provide salient cues from real-life performance situations—in this case, a virtual audience and audition. The environments were designed on the principles of 'distributed simulation', in which only a selective abstraction of environmental features are provided. The aim was to generate back-stage and on-stage environments using appropriate lighting and sound cues (e.g., CCTV footage of the audience displayed backstage and spot-lights and curtains on stage), as well as realistic, interactive virtual audiences of different types and sizes. The simulator was designed along the principles of distributed simulation (i.e., low-cost and portable, with high fidelity) to operate in two modes: (1) a recital with 24 virtual audience members; and (2) an audition situation with three 'expert' virtual judges. Having never come across such tool to train and understand performance stress, I was keen on developing and using the simulation further in order to monitor musicians' physiological and psychological stress responses, in particular in changes in the musicians' heart rate variability and their feelings of anxiety.

In addition to my PhD at the Royal College of Music, I initiated a partnership with researchers from the Electrical and Electronic Engineering, Imperial College London, U.K. that allowed me to gain expertise in signal processing using analysis tools such as Matlab. This collaboration continued throughout my PhD, followed by a position as a visiting researcher and later on as a research assistant, during which I contributed to the execution of three projects: (1) the impact of sleep deprivation on electroencephalographic (EEG) signals and cognitive performance outcome; (2) the evaluation of electrocardiographic data and EEG data in neonates with pre-natal brain injuries; and (3) the detection of quantifiable ECG metrics to identify stress states.

The first project assessed the efficacy of different EEG monitors for detecting sleep and wake in real-world environments, and the impact of sleep deprivation on changes in EEG activities and cognitive performance outcomes. In particular, for the cognitive performance task, the effect of sleep deprivation on reaction time (psychomotor vigilance task) and information processing (Stroop Test) was put under scrutiny. My responsibilities for this project involved the design of the cognitive performance protocol, the development of standardised questionnaires that supports changes in EEG patterns in response to sleep deprivation, and the guidance of a PhD student throughout the development of the study design.

The second project sought to identify quantifiable metrics of the electrical activity of the heart to detect and prevent hypoxic-ischemic encephalopathy, a brain injury caused by oxygen deprivation, or asphyxia. To this end, this project aimed to establish preventative mechanisms through the collection, analysis and interpretation of EEG and ECG signals in foetuses and neonates during their first 12 hours after birth. I collected first pilot data and carried out a systematic review of the existing literature on the utility of early heart rate variability in predicting brain injury and/or adverse neuro-developmental outcomes after neonatal encephalopathy.

In my last project, which was particularly important for my work as a PhD student at the Royal College of Music, I focused on ECG and stress detection and closely examined the relationship between physiological stress and structural complexity of heart rate variability in response to real-life performance scenarios. The framework included R-peak detection, heart rate variability detrending and the evaluation of quantitative heart rate variability metrics that are related to changes in the autonomic nervous system and the sympatho-vagal balance (for more details, see Chapter 2). Scenarios of interest were public performances (presentation and musical performance) and the application of stress indices in finance—with the aim to determine characteristics of financial indices related to human stress levels, and to establish a robust metric for the extent of 'stress' of the financial system.

Overall my work as a research assistant included the quantification and interpretation of physiological and psychological data using SPSS and Matlab, and the design of protocols and establishment of interdisciplinary experiments. Working at the department of Electrical and Electronic Engineering at Imperial College London allowed me to liaise with researchers from the field of Health Science. Electrical and Electronic Engineering and Health Science have a distinctively different understanding of how to conduct experiments and to analyse and present data using qualitative and quantitative measures. The responsibility to correspond between departments equipped me with the skills to coordinate and deliver performance outcomes by means of weekly tutorials and training sessions, in which I explained research content and methods in a straightforward fashion, allowing a mutual understanding for every research group involved.

All these experiences led to the development of my thesis in its current state; conducting my PhD thesis enabled me to gain expertise in performance science as well as electrical and electronic engineering, and I can with confidence say that my PhD thesis is a product of both, developed with great passion and dedication over the last four years.

1.2 Overview of the thesis

The overview of this thesis is as follows:

Having provided a detailed review of the concept of stress and the stress of music performance, including a published review of Dianna Kenny's book *The Psychology of Music Performance Anxiety* (Aufegger, 2013), the next chapter is dedicated to the assessment of performance stress in music, as well as methodological approaches to measuring and quantifying music performance stress. In particular, standard and state-of-the-art methods (Frequency domain analysis and multiscale sample entropy [MSE], respectively) for studying the physiological parameter, heart rate variability, is reviewed. Standard heart rate variability frequency domain analysis allows the division of the electrocardiographic (ECG) signal into clinically relevant frequency components, with the low frequencies (LF:$0.04-0.15\,\text{Hz}$) and the high frequencies (HF:$0.15-0.4\,\text{Hz}$) assumed to reflect the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS), respectively. Multiscale sample entropy (MSE) is a method which is particularly suited to examine structural complexity of time series, as it calculates entropy values directly from data; subsequently, the calculated entropy is evaluated over increasing scales (degree of averaging of non-overlapping windows in a time series). For example, a signal with no structure (white noise) will exhibit highest standard entropy (scale 1) which will then decrease with the increase in scale factor – a signature of eta with low structural complexity; on the contrary, signals with tremendous amounts of structure (e.g., pink noise) will have lower entropy than white data but will keep those levels high with an increase in scale.

Chapters 3 and 4 report a novel investigation of the physiological responses to low- and high-stress performance situations and before and during the performance from the perspective of a case study and music students. In Chapter 3, the physiological response of an expert musician was evaluated in low stress (a rehearsal) and high stress (a recital for 400 people) performance conditions and along a piece of music of varying difficulty. Chapter 4 offers further insights into the degree and peak of cardiovascular reactivity between low- and high-stress performances. Musicians' heart rate variability was monitored during a 5-minute pre-performance period and during a low- and high-stress performance; self-reported anxiety was collected prior to the events. The heart rate variability was again examined in terms of standard and state-of-the-art analyses.

Chapter 5 introduces a new approach to managing performance stress and enhance performance preparation. For this, a simulated performance space developed by the Centre for Performance Science, Royal College of Music, was employed. The simulated performance space is a training tool that combines a virtual reality display with key features of a real environment. The aim of this research was to design and test the efficacy of simulated performance environments in which conditions of *real* performance could be recreated. Advanced violin students were recruited to perform in two simulations: a solo recital with a small virtual audience and an audition situation with three 'expert' virtual judges. Each simulation contained back-stage and on-stage areas, life-sized interactive virtual observers, and pre- and post-performance protocols designed to match those found at leading international performance venues. Participants completed a questionnaire on their experiences of using the simulations.

In Chapter 6, further elaboration of musicians' perceptions and experiences of using simulated performance environments is provided. Conservatoire students performed in two simulations: a recital with a virtual audience and an audition with virtual judges. Qualitative data were collected through a focus group interview and written reflective commentaries.

In Chapter 7, data from twelve musicians who performed twice in the simulated environment are reported: once in front of three 'judges' providing positive facial and behavioural feedback and once displaying negative facial and behavioural feedback. The heart rate variability was monitored throughout the performance including a 5-minute pre-performance period while self-reported anxiety was assessed before and after. The heart rate variability was again examined in terms of standard frequency and MSE methods.

Chapter 8 summarises the main findings of the thesis, addresses limitations, and offers new directions for further research.

Chapters in the thesis have been published (in full or in part) as follows:

- Aufegger, L. (2013). Book review: D. Kenny, The psychology of music performance anxiety. *Psychology of Music, 41*, 398-401. [Chapter 1]

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The specific contribution of the research reported in the thesis is as follows:

- Literature review: Lisa Aufegger
- Design of the study: Lisa Aufegger, under the supervision of Aaron Williamon and David Wasley
- Development of materials and apparatus: Lisa Aufegger, under the supervision of Aaron Williamon and David Wasley
- Recruitment of participants: Lisa Aufegger
- Gathering of the data: Lisa Aufegger
- Signal processing of the physiological data: Lisa Aufegger, David Looney, Theerasak Chanwimalueang
- Analysis of the data: Lisa Aufegger
- Writing: Lisa Aufegger, under the supervision of Aaron Williamon, Rosie Perkins, David Wasley and Danilo P. Mandic

2 | Methodological considerations

2.1 Literature review

Having discussed the general concept of stress alongside emotion-specific autonomic behaviour, the next sections provide a literature review in order to understanding how these changes are expressed in musical performance contexts, the methodological considerations of assessing performance stress and a justification as to why I chose a particular method based on the review aforementioned.

Literature review—Performance stress in conservatoire students

Performance stress appears regardless of age and expertise and has been shown to appear alongside feelings of anxiety and increased physiological responses such as heart rate. The next sections provide a literature review of what has been done in examining performance stress, in particular in conservatoire students. The review ends with a summary of the findings (Table 2.1 and 2.2) as well as an explanation of my method chosen. In addition, at the end of this chapter, I provide a short digression concerning performance stress in young and professional musicians in order to offer a complete overview of the stress research that has been done in performance science.

A first study investigating physiological responses in music students was done by Craske and Craig (1984). They asked 40 21-year-old piano students to perform a memorised piece both alone and in front of an audience (consisting of peer students). Questionnaires administered were the Confidence as a Performer Scale (Appel, 1976), the SAI-Y1 (Spielberger et al., 1983) and the Expectations of Personal Efficacy for Musicians Scale (sub scales; level and strength of self-efficacy: Kendrick, Craig, Lawson, & Davidson, 1982). All three were completed 10-15 minutes prior to the performance. Furthermore, the Subjective Units of Distress Scale (Wolpe, 1969) given before and after the performance, as well as the Performance Anxiety Self-statement Scale (Kendrick et al., 1982)—completed after the performance, was collected. Heart rate was monitored at 10-second intervals 100, 40, and 10 seconds prior to and 120, 140, 260 and 400 seconds after the first note played. Skin-resistance level was taken one minute before and after the first note was played and one minute prior to the final note. Breaths per minute were calculated for two time periods: (1) from the start of the recording until the first note played; and (2) from the first note played until the end of the performance. Prior to the analysis, participants were grouped into low- and high-anxious musicians. Multivariate analysis demonstrated an effect of group and condition (performance alone versus in front of an audience), with high-anxious musicians showing higher levels of state anxiety, negative self-statements, as well as lower levels and strength of self-efficacy. Performing alone and in front of an audience caused a significant effect on the state anxiety scores and the Subjective Units of Distress Scale. High-anxious musicians produced significantly lower scores on self-efficacy when performing alone and in front of an audience, whereas no such effect was found in low-anxious musicians. Significantly higher heart rate, skin resistance and responses and breathing was detected during the performance in front of the audience than when performing alone, while no group effect for heart rate and breathing was observed. Looking at groups separately, significant correlations between psychological and physiological measures were detected between high-anxious musicians, heart rate during both the private and public performance, self-efficacy and the Retrospective Subjective Units of Distress Scale.

Abel and Larkin (1990) asked 22 20-year-old music students (no indication of the instrument played) to perform in a laboratory setting (baseline measure) followed by a performance in front of a jury (between two to seven private teachers/assistants), two to six weeks afterwards. Questionnaires given were the abbreviated State and Trait Anxiety Inventory, state form (Spielberger et al., 1983), the Personal Report of Confidence as a Performer (Appel, 1976) and a quick self-report on confidence. All questionnaires were completed before, while the State and Trait Anxiety Inventory-state form was also administered after the performance. The baseline measure consisted of a 6-minute period where students had to sit quietly while heart rate and blood pressure was taken. No performance was required, instead participants had to carry out an arithmetic test, followed by a 6-minute resting period, a concepts challenge and another 6-minute resting period. The heart rate was taken 12 times per minute throughout the baseline measure and five minutes (i.e., warm up period) and two minutes (i.e., call to go on stage) prior to the performance. Blood pressure was taken four times during the 5-minute heart rate monitoring. Results demonstrated significantly higher scores for the State and Trait Anxiety Inventory-state form in the two anticipatory periods compared to the baseline measure and no difference neither for the Personal Report of Confidence as a Performer nor for the self-report on confidence. Heart rate and blood pressure (diastolic and systolic) was significantly increased from the baseline measure to the first to the second anticipatory period. The second period was significantly positively correlation between the heart rate and the Personal Report of Confidence as a Performer, while a negative correlation occurred between the heart rate and the self-report on confidence.

Fredrikson and Gunnarsson (1992) assessed performance stress, heart rate and endocrinological reactions, including cortisol, and (nor-)epinephrine in performances by string players. Psychological assessment was carried out by the Personal Report of Confidence as a Musician—a questionnaire based on the Report of Confidence as a Speaker (Paul, 1966), dividing the sample into low-anxious and high-anxious musicians. Heart rate was monitored for three minutes before the performance (while sitting), the first six minutes during the performance (standing), and three minutes after the performance (sitting). Endocrine measures were collected via urine samples one hour before and 30 minutes after musicians were asked to perform in two conditions: with no audience and in a public concert. Peak heart rate was detected during both no audience and the public concert. While a group effect (low- versus high-anxious musicians) was found for heart rate and self-reports, with higher degrees of reactivity exhibited for high-anxious musicians, no such pattern occurred for the endocrinological responses. Significantly elevated endocrinological responses were detected prior to the public performance compared with the no audience condition, as well as significantly lower levels of self-confidence.

Brotons (1994) compared an open versus a double blind jury condition in 64 24-year-old music students playing different instruments. For the open jury condition, students were asked to perform in front of a jury, whereas the double blind jury condition consisted of an audio recording of students' performance that was rated by evaluators, where both the students and the evaluators had no information about each other. Psychological stress responses were investigated by the State and Trait Anxiety Inventory-state form (Spielberger et al., 1983). Heart rate was monitored prior to and during performance, including the monitoring of a non-performance day as baseline comparison. The results demonstrated significantly increased State and Trait Anxiety Inventory-state form and heart rate during both jury conditions compared with the baseline measurement, while no difference between the jury conditions was found. No indication of peak heart rate (before or during the performance) was provided.

Yoshie, Kudo, Murakoshi, and Ohtsuki (2009) investigated 18 20-year-old pianists performing a piece from memory during a rehearsal and a competition. A visual analogue mood scale (Cella & Perry, 1986) was filled out before each condition, while heart rate, sweat rate, and electromyographic activity of upper extremity muscles was monitored (and sampled at 1000 Hz) during the performance. The results revealed that the self-reported anxiety was significantly higher prior to the jury condition than the rehearsal condition, an effect that was also seen in during the competition in the heart rate and the sweat rate. Furthermore, a greater electromyographic magnitude was found for the competition condition. No correlation analysis was carried out.

Studer et al. (2012) asked 67 23-year-old students playing different instruments to attend to a baseline measure and a private and a public performance, including an audience of approximately 10 members of peers and two experts. The State and Trait Anxiety Inventory-state form (Spielberger et al., 1983) was given before the performance, while subjective reports on affective and physiological symptoms (e.g., anxiety, tension, shortness of breath) were administered before and after a 10-minute pre-performance period. Physiological assessment prior to the performance included the partial pressure of end-tidal CO_2 (PET_{CO2}), heart rate and heart rate variability, minute ventilation (V'E), the percentage of ribcage contribution to the inspiratory volume (%RC), the tidal volume variability (T_{VV}), the inspiratory time (T_I), expiratory time (T_E), total breath duration (T_{TOT}), the duty cycle (T_I/T_{TOT}), indicating inspiratory timing, the inspiratory volume (V_I), the mean inspiratory flow, which is an index of inspiratory drive (V_T/T_I), and the physical activity (accelerometer data). The State and Trait Anxiety Inventory-state form was significantly higher before the public compared to the private performance. This was also confirmed by self-reports on physical symptoms. Students with higher MPA scored higher in both inventories during the public performance. A significant increase was, furthermore, found in heart rate variability, T_E, T_{TOT} and T_I/T_{TOT} during the high-stress condition. Neither an increase in PET_{CO2} was detected nor a significant correlation between MPA scores and physical features was observed.

Table 2.1: Physiological and psychological assessment in music students during evaluative performance contexts.

Author	*Subjects*	*Age*	*Instrument*	*Condition*	*Psychological Assessment [1]*
(Craske & Craig, 1984)	40	21.5 (*SD*=4.15)	Piano	Private vs. public performance	STAI-Y1 [b], SUDS [a], SE [b]
(Abel & Larkin, 1990)	22	19.5 (*SD*=N/A)	N/A	Baseline vs. jury	STAI-Y1 [b], PRCP [b]
(Fredrikson & Gunnarsson, 1992)	19	N/A	String	Private vs. public performance	PRCM [b], PRCS [b]
(Brotons, 1994)	64	24.02 (*SD*=8.24)	Various	Private vs. jury	STAI-Y1[b]
(Yoshie, Kudo, et al., 2009)	18	26.7 (*SD*=6.3)	Piano	Rehearsal vs. competition	VAS [b]
(Studer et al., 2012)	67	23.3 (*SD*=3.5)	Various	Private vs. jury	STAI-Y1 [b]

Table 2.2: Physiological and psychological assessment in music students during evaluative performance contexts [cont.]

Physiological Assessment [2]	*Details heart rate*	*Results [1]*	*Results [2]*	*R*
HR [b,d], SRa [b,d], SRb [b,d]	Monitored 6/min	STAI-Y1 ↑, SUDS ↑, SE ↓	HR [d] ↑, SRa[d] ↑, SRb[d] ↑	n.s.
HR [b,d], BP [b,d]	Monitored 12/min	STAI-Y1↑, PRCP⟷	HR [b]↑, BP [b] ↑	n.s.
HR [b,d], Cortisol & (Nor-)Epinephrine [b,a]	N/A	PRCM↓, PRCS↓	HR [d]↑, Cortisol [b]↑, (Nor-)Epinephrine↑	n.s.
HR [b,d]	N/A	STAI-Y1↑	HR [b]↑	n.s.
HR [d] SRa [d], EMG [d]	sampled at 1000Hz	VAS↑	HR↑, SR↑, EMG↑	N/A
HR [b], Breathing [b]	N/A	STAI-Y1↑	HR↑, Breathing↑	N/A

STAI-Y1=State and Trait Anxiety Inventory, state form (Spielberger et al., 1983); **SUDS**=Subjective Units of Distress Scale (Wolpe, 1969); **SE**=Expectations of Personal Efficacy for Musicians Scale (Kendrick et al., 1982); **PRCP**=The Personal Report of Confidence as a Performer (Appel, 1976); **PRCM/PRCS**=The Personal Report of Confidence as a Musician and the Report of Confidence as a Speaker (Paul, 1966); **CSAI**=The Competitive State Anxiety Inventory (CSAI, modified version; (Martens et al., 1990); **PAQ**=The Performance Anxiety Questionnaire (Cox & Kenardy, 1993); **VAS**=Visual analogue mood scale (Cella & Perry, 1986); **HR**=Heart rate; **BP**=Blood Pressure; **SF**=Sampling frequency; **SRa**=Skin resistance **SRb**=Skin response; **[b]**=before; **[d]**=during; **[a]**=after; ↑,↓,⟷=Increase, decrease, no change of markers associated to the high-stress condition (e.g., public concert, competition, etc.); **R**=Correlation between physiological and psychological measures.

2.1.1 Methodological considerations

Heart rate variability

Overall, studies have shown that musicians experience increased heart rate either before or during performance or both in front of an audience and audition panel, respectively. The heart rate was significantly different from the rehearsal and musicians' baselines and occurred typically alongside elevated feelings of anxiety.

Based on the studies available, however, it is difficult to draw conclusions about the degree and timing of musicians' cardiovascular reactivity to acute psychosocial stress for at least two methodological reasons. Firstly, the studies conducted reported heart rate rather than heart rate variability. Standard heart rate variability analysis allows the division of the electrocardiographic (ECG) signal into clinically relevant components associated with the sympathetic nervous system and the parasympathetic nervous system. The importance of analysing heart rate variability became evident when variability was found to be a strong predictor of mortality after an acute myocardial infarction (Malik et al., 1996).

Secondly, studies in music to date have examined different pre-performance periods, ranging anywhere from 100 s to 5 min beforehand, and have monitored heart rate at different intervals, which impacts the capacity to detect subtle changes. Recordings of heart rate and specifically variability, however, should be standardised to a minimum of 5-minute epochs to assure consistent assessment across studies.

These recommendations were formulated by the European Society of Cardiology in collaboration with the North American Society of Pacing and Electrophysiology (Malik et al., 1996). Both successfully constituted a Task Force with the main aim to develop standards of defining common terms in cardiovascular research, specifying standard methods of measurement and to determine future areas of research. Members of the Task force contain researchers across a wide range of different expertise, including the fields of mathematics, engineering, physiology, and clinical medicine. Their guideline allows appropriate comparisons and observations, promote and in-depth understanding and interpretations, and inspire to lead to further progress across different research fields.

How to collect and analyse heart rate variability

Bio-signals refer to any signals that have a biological/biomedical origin. This can imply electrical activity from the heart (ECG), endocrinological responses, electrical activity from the body's muscles (EMG) and electrical activity from the brain (EEG). Current technological tools allow a rigorous and precise assessment of these bio-signals, however, they also came alongside a variety of different methodological considerations for a meaningful interpretation. The next sections look at these considerations, discussing the optimal steps required for a sufficient data acquisition, effective ways of signal processing, and the appropriate methods to analyse them.

Heart rate variability is usually monitored by the electrocardiogram (ECG), a non-invasive method that detects the regularity of beat-to-beat (R-R) fluctuations (Berntson & Cacioppo, 2004). ECG captures the atrial depolarisation (P wave), the depolarisation of the right and left ventricles (QRS complex) and the recovery of the ventricles (T wave), with another P wave completing the full cycle. The index of interest is the R-R intervals—the time difference between one ventricular depolarisation to another (Kamath, Watanabe, & Upton, 2013). ECGs can be obtained using electrodes placed on the skin's surface that either are physically connected to an external recording device or connected by a wireless belt equipped with sensors and strapped around designated body locations. The signal is then transformed from a continuous signal into a discrete one (Malik et al., 1996). The accuracy of the signal depends on the recorded sampling frequency, known as the number of samples per unit of time, and the adequate preparation of the equipment to monitor the user (e.g., low sampling frequencies (100 Hz) lack a complete reconstruction of the recorded signal (Kamath et al., 2013).[1]

[1] The sampling frequency of ECG should be of at least 250 Hz (Nyquist–Shannon sampling theorem: Malik et al., 1996; Nyquist, 1928). No benefits are gained of sampling above 2000 Hz.

In the research reported in this thesis, I collected R-R intervals by means of the The Zephyr BioHarness (ADinstruments). The Zephyr BioHarness (weight 35g; 80x40x15 mm) is a simple belt (50g, 50 mm width) with electrode sensors accommodated within the chest strap that captures heart rate, breathing frequency, skin temperature, activity and posture in real time or offline. It further possesses is an internal memory of 480 hours and a battery life up to 10 hours. The equipment contains great potential for the evaluation of stress signatures and has been shown reasonable adequate in terms of reliability and validity. This was shown by two studies carried out by Johnstone, Ford, Hughes, Watson, and Garrett (2012b) and Johnstone, Ford, Hughes, Watson, and Garrett (2012a). In both studies, they compared heart rate, breathing frequency, accelerometers and skin temperature measured by the BioHarness with other well-established devices, such as the Polar T31 (Polar Electro, Kemple, Finland) or a face respiration mask called Spirometer (version 3B; Cortex Medical, Germany). Ten participants were asked to complete a simple treadmill protocol designed by the authors. The results showed a strong correlation between the assessed variables and the subjects, making the BioHarness an effective tool collecting, processing and evaluating bio-signals.[2]

Other factors adulterating the quality of the data are artifacts or ectopic beats (considering a healthy subject). The former are occurring beats outside of the patterns of the R-R fluctuations, the latter are extra beats that results in shortened R-R intervals, a compensational delay and an extended R-R interval, leading to a minimised stroke volume that affects at least 10-30 beats. Artifacts can be caused by:

- Power line interference
- Muscle contractions

[2] Other devices that have been developed and and appear promising by offering non-invasive and wirelessly working measurements is the 'Droid Jacket' or also so-called 'Magic Vest' (Foundation Don Gnocchi), the 'LifeShirt' (VivoMetrics, Rae Systems) or 'HealthVest' (SmartLifeTech: Heilman & Porges, 2007). Studies such as the one by Kent et al. (2009) compared the LifeShirt with the Polar belt (Sport Tester, RS600i, Kempele, Finnland) and a pneumotachograph (COSMED quarkB2, Rome, Italy), and investigated variables such as respiratory rate, expiratory time and heart rate. The results revealed a low variation in respiratory rate between devices, yet there was a significant effect in expiratory time and heart rate, in particular between the LifeShirt and the pneumotachograph (COSMED quarkB2, Rome, Italy) during low exercise intensity. According to the authors, future studies may apply the LifeShirt outside the laboratory setting, yet consider an additional validation when assessing the cardiovascular output for low- to moderate stress exposure.

- Electrode contact noise
- Excessive body movement
- Baseline wandering
- Noise generated by electronic devices used in signal processing circuits
- Electrical interference external to the subject and recording system
- High-frequency noises in the ECG
- Breath, lung, or bowel sounds contaminating the heart sounds (PCG).

These additional noises may mislead the result if not spotted before further analysis (Nayak, Soni, & Bansal, 2012).

Noise in heart rate variability data can be displayed by means of geometrical visualisation, such as the Poincaré plot; a scatter plot that indicates the dynamic of the heart rate embedded in a two-dimensional visual graphic (Combatalade, 2010). Thus, each R-R fluctuation is plotted against the next one and shows the deviations of short- and long-term R-R fluctuations. The plot (also called scattergram) can be evaluated quantitatively through the calculation of the standard deviation indexes of the plot, and provides a summary as well as a detailed information of each beat-to-beat behaviour of the heart (Hsu et al., 2012). A healthy heart displays a '…cigar-shaped cloud of points oriented along the line of identity' (Voss, Schulz, Schroeder, Baumert, & Caminal, 2009, p. 285) and a long-term standard deviation of approximately 125 ms, while a reduction to 85 ms illustrates ventricular tachyarrhythmia.

If noise appears above a threshold of 2%, filter methods should be applied (Peltola, 2012). The commonest filter methods are the Butterworth filter, the cubic spline interpolation and the Median filter. The Butterworth filter is defined by two parameters: the cut-off frequency and the order. While the cut off frequency delimits the boundary of the frequency within a signal, the order determines the level of sharpness from pass band to stop band. Pass and stop bands are represented by a range of frequencies, being either let through or rejected and produces—combined with the cut-off frequency—a monotonic filter response. The more noise in the data, the higher the order that should be applied (Robertson & Dowling, 2003). The cubic spline interpolation divides a signal into small subsections and connects approximations between oscillations (i.e., piecewise polynomial interpolation), reassuring an overall smoothness (Haghighi & Roohi, 2012).[3] The median filter combines midpoint values of the signal, making the data less vulnerable to outliers.[4]

The application of the filter methods depends on the quality of the date (e.g., for noisy data with many outliers, the median filter is recommended). All three filter methods facilitate the further processing of the ECG data according to the Task Force by means of: (1) Time domain analysis (Billman, 2011; Malik et al., 1996); and (2) Frequency domain analysis (Kamath et al., 2013).

Time domain analysis

The time domain analysis examines physiological signals and their progression with respect to time. It determines the average R-R (or N-N) intervals (AVNN), their standard deviation (SDNN), the root mean square of successive differences of R-R intervals (RMSSD) or the (percentage of) difference between adjacent NN intervals that are greater than 50ms.[5] Each parameter gives insights into the degree of the sympatho-vagal balance (see Table 2.3). In a relaxed state, for instance, the AVNN ranges between .6 and .8 seconds, with small SDNNs and RMSSD and a larger percentage of NN50. Time domain analysis does not require a high degree of 'stationarity' [6] of the data, it only provides an overall marker of the heart rate variability, failing to investigate R-R intervals based on their frequency distribution (Kamath et al., 2013; Malik, 1996; Stein et al., 1994).

[3]Interpolation methods are also able to replace any abnormal R-R intervals by new interpolated R-R intervals (Peltola, 2012).

[4]Another interesting filter is the FIR filter, which removes the data from baseline drift and high-frequency noise. It filter between 0.5 and 35 Hz, using 8000 coefficients. Due to its stability and its simple application, it makes it very attractive compared to other filter methods. However, the main disadvantage is the large number of coefficients needed, making its application rather time-consuming (Lim, 1990; Rabiner & B., 1975).

[5]N-N (Normal-to-Normal) and R-R (R wave-to-R wave) intervals are equivalent.

[6]Stationary signal have probability distributions (statistical properties) which are constant in time.

Table 2.3: Features extracted from the Time domain analysis (Kleiger et al., 2005; Malik et al., 1996; Stein et al., 1994).

Abbreviation	*Definition*	*Function*
AVNN (ms)	Average of N-N intervals for period interest	Can convert to average heart rate of N-N intervals (heart rate=60,000/AVNN)
SDNN (ms)	Standard deviation of N-N intervals for period of interest	Reflects total heart rate variability
SDANN (ms)	Standard deviation of AVNN for 5-minute intervals for period of interest	Reflects primarily circadian heart rate variability
pNN50 (%)	Percentage of N intervals >50ms different from previous (N-N) for period of interest	With normal sinus rhythm reflects vagal activity
RMSSD (ms)	Root mean square of successive differences of N-N intervals for period of interest	With normal sinus rhythm reflects vagal activity
CV	Average coefficient of variance (SD/Mean) for 5-minute intervals for period of interest	Reflects average short-term heart rate variability normalised by heart rate

Frequency domain analysis

The Frequency domain analysis investigates R-R fluctuations (i.e., heart rate variability) in terms of their frequency spectrum (Kamath et al., 2013; Malliani, 1999). Stress is managed by the autonomic nervous system (ANS). In particular, a reaction to stress can be characterised by the interactions between two ANS components: the parasympathetic and sympathetic nervous systems (PNS and SNS). The interaction between the sympathetic nervous system and the parasympathetic nervous system (i.e., SNS/PNS) have been shown to influence the temporal fluctuations of the peak-to-peak times in the electrocardiogram (ECG)—the R-to-R (RR) interval, known as heart rate variability. The frequencies are detected from the power spectral density (PSD), a measure that represents signals as frequency distributions. Established frequencies components consist of low frequencies (LF) and high frequencies (HF). LFs are those observed between $0.04 - 0.15$ Hertz (Hz) and are associated with the SNS and baroreceptor reflex (i.e., blood pressure). HFs ($0.15 - 0.4$ Hz) are believed to provide information of the vagal modulation (i.e., PNS) and respiratory sinus arrhythmia (alterations in heart rate variability due to naturally occurring breathing: Berntson & Cacioppo, 2004). The ratio between the LF and HF power, the LF/HF ratio, indicates the global sympathovagal balance.[7]

[7] In long-term recording, a LF/HF ratio above 4.8 is considered to reflect the SNS and below 1.3 the PNS activity (the baseline LF/HF value is considered to be around 1.2: Billman, 2013; Milicevic, 2005).

Other less investigated frequencies are the ultra low (1.15x10-5 and 0.0033 Hz) and very low frequencies (0.0033 and 0.04 Hz). Ultra low frequencies are assumed to reflect neuroendocrine rhythms and are obtained in long-term recordings. Very low frequencies are believed to define the renin-angiotensin system (i.e., blood pressure regulation), the chemoreceptor and the thermoregulatory activity.[8] Within shorter recordings (5-10 minutes) it has also been suggested to represent negative emotions, such as worry and rumination (Table 2.4: Berntson et al., 1997; Bilge et al., 1999; Cacioppo et al., 1994; Stein et al., 1994; Taylor & Bogdan, 1998).

The minimum duration of ECG recordings should be of at least '. . . 10 times the wavelength of the lower frequency bound of the investigated component' (Malik et al., 1996, p. 13). For instance, to process HF and LF, 1 to 2 minutes of data are required, while the calculation of the ratio requires short-term recording of 5 minutes (Malik, 1996).

Table 2.4: Features that can be extracted from the Frequency domain analysis (Malik et al., 1996; Stein et al., 1994).

Abbreviation	*Definition*	*Function*
TP	Total power over measured period	Reflects total heart rate variability
ULF	Ultra low frequency power measures rhythms greater than 5 minutes	Reflects circadian heart rate variability
VLF	Very low frequency power measures rhythms between every 25 s and every 5 minutes	Reflects vagal and renin-angiotensin system effects on heart rate
LF	LF measures heart rate rhythms from 2.5 to 9 cycles/minute	Reflect combination of SNS and PNS influences. Captures baroreflex rhythms
HF	HF captures variations in heart rate due to respiratory sinus arrhythmia at 9-14 cycles/minute	Averaged over 5-minute periods or less. Under normal circumstances reflects vagal activity
LF/HF	LF/HF averaged over 5-minute periods or less	Purpose to reflect SNS/PNS balance
LFnu	[LF/(TP-VLF)] for the measured period (5 minutes or less)	Purpose to reflect the SNS activity
HFnu	[HF/(TP-VLF)] for the measured period (5 minutes or less)	Purpose to reflect the PNS activity

The most commonly applied methods to compute PSDs are the Fast Fourier Transformation (FFT) and the autoregressive model estimation (AR: Malliani, 1999). The area of Fast Fourier Transformation first arose through the development of the Cooley-Tukey Fast Fourier Trans-

[8]The chemoreceptor activity transforms a chemical signal into an action potential; the thermoregulatory activity reassures a certain body temperature.

form in the year 1965. Since then linear filtering and Fourier transform has been a key application within the field of signal processing, including telecommunications, medical electronics, radar or radio astronomy (Duhamelm & Vetterli, 1990). The importance of the FFT is highlighted in the data length, with the FFT enabling the length to be divided into subsections in order to apply its algorithm. The FFT usually assumes an a priori understanding of frequency bands of interest. The AR is more complex to carry out, yet...decompose the overall spectrum into single spectral components [...] providing automatically the central frequency and associated power without the need for a priori assumptions' (Montano et al., 2009, p. 73). The method used depends on the design of the study. Frequency domain analysis requires 'stationary' data, and ideally an infinite number of samples. Heart rate variability, however, is only collectable in blocks (or time windows) and contains outliers (or non-harmonics) produced by artifacts or ectopic beats. This causes a 'frequency leakage', a misinterpretation of the data due to limited time windows and outliers. One way to minimise frequency leakage is to filter the data. Lastly, frequency domain analysis offer a better representation, however, their disadvantage is the requirement of a '...strong periodicity of the numerous superimposed short- and long-term physiological oscillations' (Voss et al., 1996, p. 420).

A new approach to analyse heart rate variability drawn from complexity science

Measures used in complexity science are non-linear and based on the concept that systems are unpredictable, complex and infinitely diverse. To date, systems have been viewed as a product of a clear-cut cause-and-effect link that is determined by negative feedback and the goal of maintaining or regaining equilibrium (i.e., homeostasis). In doing so, outcomes are determined, intentional and chosen (Stacey, 1995). Most phenomena, however, are more complex—producing responses that are partly emergent and partly intentional, caused by spontaneous self-organization and creative self-destruction. They can be unexpected and disorderly, driven by negative but also positive feedback. The domain of complexity science considers and evaluates these aspects by investigating the biosignal in terms of linearity, disorder (i.e., complexity) and magnitude (i.e., scale)—determined by: (1) abrupt alterations; (2)

nonlinear oscillations; (3) complexity; (4) self-similar dynamics (i.e., fractal anatomies); or (5) hysteresis. Abrupt alterations are sudden onsets of a seizure or irregular oscillation, which cause unexpected changes (i.e., bifurcations: Goldberger, 1996, 2006; Goldberger, Rigney, & West, 1990). These changes are furthermore regulated by a complex network and feedback system, including fractal anatomies, self-similar dynamics and past input (Goldberger et al., 2002).

Fractals anatomies and self-similar dynamics are referred as to '…irregular geometric objects that display self-similarity' (Goldberger et al., 2002, p. 2466). Fractal anatomies encompass a wide composition of (sub-)units at different scales, resembling the larger unit in dynamic and structure (i.e., self-similar dynamic). This can be found in natural phenomena, such as mountain ranges, coast lines, but also DNA, blood and pulmonary vessels, heart rate, or even psychological subjective perception (Pincus & Goldberger, 1994; Tan, 2013). In terms of cardiovascular physiology, fractals can be structural, including vascular, muscular, electrical, and connective tissue characteristics and dynamical, such as the regulation of the heartbeat fluctuations ore the beat-to-beat pressure fluctuations (Iannaccone & Khokha, 1996). Both have the main function of quick and effective transport over complex, spatially distributed networks (Goldberger et al., 2002). With age, disease, or other exposure to maladaptive circumstances, these structures have been shown to degeneration in terms of their structural complexity. Usually, cardiac fractal-like processes generate irregular fluctuations, which exhibit self-similar properties across multiple time scales. Studies evaluating this 'scaling behaviour', however, have shown that both short and long-range (fractal) correlation properties are significantly altered, resulting in a loss of structural complexity. As such, with increased age or disease, both short and long-range (fractal) properties significantly alter, resulting in a loss of structural complexity (Costa, Goldberger, & Peng, 2002).

R-R fluctuations have been, so far, quantified either deterministically (i.e., predictably) or stochastically (i.e., randomly). While the former is expressed in mathematical terms, excluding 'latent' and unpredictable parameters (e.g., noise), the latter describes the system by its probabilities. However, according to complexity science, cardiovascular outputs are most likely a combination of both, involving a '…multitude of spatial and temporal scales. . . [which helps to be]. . . more adaptive. . . [towards]. . . external changes' (Thuraisingham & Gottwald, 2006, p. 2). The degree of complexity can be evaluated using, for instance, sample entropy measures.

Sample Entropy A family of statistical measures, named approximate entropy, was introduced by Pincus (1991) in order to quantify the regularity of short and noisy time series. The concept is based on the computation of frequency of occurrence of similar patterns in the data, whereby a pattern is defined by data segments of equal length called the delay vectors. The length of these delay vectors reflects physical properties in the data, such as the embedding dimension and 'sufficient information'. The similarity of two delay vectors is assessed based on their distance and a ratio of a number of similar delay vectors and the total number of delay vectors (for a given distance) plays the role of relative frequency, a concept closely related to probability. The original approximate entropy algorithms considers self-matching sequences, to avoid the problem of $\ln(0)$ in the calculations, however, this introduces bias in the entropy value which makes approximate entropy overly sensitive to the length of the time series. To mitigate the lack of consistency in the approximate entropy estimates, Richman and Moorman (2000) introduced the sample entropy algorithm, which calculates the conditional probability that two sequences of m consecutive data points, which are similar to within a tolerance level r, will remain similar when the next consecutive points are included (self-matches are not considered). This modification makes sample entropy largely independent of the length of a time series length and equips it with additional consistency over a wide range of dynamically diverse time series and operating parameters.

For time series $\{x(n)\} = \{x(1), x(2), \ldots, x(N)\}$, the SampEn can be calculated based on the following steps:

1. Initially, $(N - m)$ delay vectors of embedding dimension m are formed as $X_m(i) = [x(i), x(i+1), \ldots, x(i+m-1)]$ where $i = 1, 2, \ldots, N - m$. These delay vectors represent m consecutive values of a data stream x, commencing with the i-th point.

2. The distance between any two delay vectors $X_m(i)$ and $X_m(j)$ is defined as the maxi-

mum norm:

$$d\left[X_m(i), X_m(j)\right] = \max_{k=1,\ldots,m} \left\{ |x(i+k-1) - x(j+k-1)| \right\}.$$

3. For a given $X_m(i)$, the number of similar delay vectors is counted ($1 \leq j \leq N-m, j \neq i$), denoted as B_i, such that $d\left[X_m(i), X_m(j)\right] \leq r$.

4. For $1 \leq i \leq N-m$, the quantities $B_i^m(r) = \frac{1}{N-m-1} B_i$ and $B^m(r) = \frac{1}{N-m} \sum_{i=1}^{N-m} B_i^m(r)$ are calculated.

5. Similarly, $B_i^{m+1}(r)$ and $B^{m+1}(r)$ are calculated for the embedding dimension $m+1$.

6. Thus, physically $B^m(r)$ is the probability that a similar pattern will be found in the set of delay vectors with embedding dimension m, whereas $B^{m+1}(r)$ is the probability that two sequences will match for $m+1$ points.

7. Finally, Sample entropy is computed by:

$$SampEn(r, m, N) = -\ln \left[\frac{B^{m+1}(r)}{B^m(r)} \right]$$

where r is the tolerance level, m is the pattern length and N is the length of the time series.

Note that a comparison of structural complexity among time series can only be performed for fixed values of r, m and N. The parameter r is usually set as a small percentage of standard deviation of the original time series. This equips sample entropy with scale invariance, that is, robustness to uniform scaling of signal magnitudes or DC offset. Various theoretical and empirical studies have shown that the recommended parameter values: $m = 1$ or 2 for the embedding dimension, $r = [0.1, 0.25]$ for the percentage of standard deviation, and 10^m to 20^m data points, provide sufficiently reliable sample entropy estimates.

In summary, the entropy measures evaluate biosignals in terms of their degree of 'regularity' and 'complexity' (Voss et al., 1996, 2009). First introduced by Pincus (1991), aiming to improve the Kolmogorov entropy notions—an approach that is more suitable for phenomena of less dimensionality—his 'approximate entropy' calculates the likelihood of patterns that appear to be similar. While healthy participants exhibit an approximate entropy of heart rate complexity ranging around 1.0, patients that suffered a myocardial infarction reveal an approximate entropy of approximately 1.2 (Mäkikallio et al., 1999). A modified version of the approximate entropy is the sample entropy. The sample entropy evaluates sequences of heart rate dynamics based on their degree of similarity (within a pre-defined tolerance), as well as whether the degree remains stable after e.g., a consecutive data point has been included. Low sample entropy refers to extreme regular physiological time series, high sample entropy represents more complexity and highest sample entropyE are usually assumed to occur in stochastic physiological data (Pincus, 1991; Pincus & Goldberger, 1994; Weippert, Behrens, Rieger, & Behrens, 2014). Decreased sample entropy has been shown to appear alongside cardiovascular diseases (Shin et al., 2006; Tuzcu, Nas, Borklu, & Ugur, 2006), aging (Takahashi et al., 2008) and performance stress (Williamon, Aufegger, Wasley, Looney, & Mandic, 2013). Both the approximate entropy and the sample entropy, however, require stationary and noise-free data and are dependent on the data windowing and outliers and only evaluate one scale (Voss et al., 2009). Moreover, sample entropy methods have been extensively used to assess the complexity and regularity of physiological time series. However, it has been shown that such methods may produce inconsistent results due to the involved temporal fluctuation in physiological signals, which are not accounted for in these standard algorithms.

Multiscale sample entropy The multiscale sample entropy extends the conventional sample entropy measure by allowing the investigation of the complexity of time series at different resolutions, or time scales (i.e., by setting a scale factor parameter: Costa et al., 2002). Thus, multiscale sample entropy analyses are predicated upon the following: (1) the complexity of the human system is a reflection of a constantly changing environment and (2) can be detected by exploring the underlying non-linear dynamics in biomarkers, such as heart rate variability, at different scale factors (Gao et al., 2013). The multiscale sample entropy assesses the structural richness of the data and has been able to demonstrate that: (1) greatest complexity—due to a high degree of correlated properties—is observed in healthy and young subjects compared to their older counterparts; and (2) higher scale factors generated a better discrimination coefficient between signals of different physiological states. As such, multiscale sample entropy is able to distinguish between physiological time series with different degrees of complexity and more rigorous definitions of time scales (Ahmed & Mandic, 2012). Nevertheless, also the multiscale sample entropy requires clean and stationary data and loses consistency as the amount of data points diminish (Voss et al., 2009).

Summary and approach used in this thesis Physiological signals, such as heart rate variability are analysed by linear and non-linear methods, such as time domain analyses, frequency domain analyses or entropy measures. Time domain analysis employs statistical (mean, standard deviation) or geometric methods to inform about a physiological state. Frequency domain analysis investigated specific frequency bands and their amplitude. The most commonly investigated frequency bands are the low and high frequencies, both associated with the sympathetic and parasympathetic nervous system and indicating the sympatho-vagal balance (Peltola, 2012). A more recent method is sample entropy measures—a nonlinear methods derived from the complexity science. So far, (biological) systems have been believed to work towards homeostasis by assuming a linear and high predictable cause-effect outcome, generating a proportionate input or output. Complexity science accuses these theories as too simple and one-sided. Instead, they propose a 'homeostasis revisited'—a stability reached by a complex dynamic of stationarity, nonlinearity (i.e., unpredictable interactions within a system) and multiscaled organisation (i.e., fluctuation of different fractal properties). The main aim of (multiscale) sample entropy is to detect dynamical structures and to develop predictive models and theoretical frameworks (Newman, 2003).

Noteworthy to mention, all three methods have their limitations; the time domain analysis only offers a preliminary insight into heart rate variability; the frequency domain analysis assumes to represent either the SNS or the PNS activity of the ANS, yet studies were not always in agreement within the condition tested. While the LF is believed to show increased power during physical and mental stressful tasks, a pronounced activity was also detected during more relaxed conditions, such as sleep or deep breathing (Houle & Billman, 1999; Rahman, Pechnik, Gross, Sewell, & Goldstein, 2011). Moreover, some studies observed an opposite effect, a decreased LF power during taxing conditions (Billman, 2013). The sample entropy method offers a fruitful and sophisticated statistic to expand our knowledge of cardiovascular oscillations and their alterations alongside increased age or cardiovascular disease (Oxenham & Sharpe, 2003; Strait & Lakatta, 2012). Nevertheless, studies on sample entropy are inconsistent and while this method may lead to a deeper understanding of cardiovascular data, it is not yet fully understood how this method is exactly related to physiological control (Tan, 2013; Tan, Cohen, Eckberg, & Taylor, 2009).

Lastly, all three methods have been applied in previous research without the acknowledgement of the influence of breathing. Reasons for this are manifold: Firstly, the limitation of adequate equipment makes it difficult to measure the breathing rate over a longer period of time (Sobron, Romero, & Lopetegi, 2010). Secondly, the mechanism behind breathing as well as its individual variations along time and volume dimensions are complex and are particularly difficult to extract when playing an instrument (e.g., additional influence of movements: Wientjes, 1992). Moreover, while the respiration sinus arrhythmia seems to be '...well-preserved in young and healthy individuals, it is diminished in older individuals with various diseases whose conditions are complicated by cardiovascular diseases, diabetes mellitus, and the like. In this context, the respiration sinus arrhythmia represents a 'cardiac age' or a 'cardio-pulmonary reserve [and should therefore be considered as an additional signal processing approach when analysing cardiovascular responses to stress]' (Yasuma & Hayano, 2004, p. 699).

In the studies that follow in this thesis, heart rate variability was analysed using the frequency domain analysis and the (multiscale) sample entropy analysis. The rationale for choosing the frequency domain analysis and the (multiscale) sample entropy method is based on the provided evidence of its feasibility based on the Task Force guidelines. The Task Force contains of wide range of researchers with different expertise, including the fields of mathematics, engineering, physiology, and clinical medicine, and offer a step by step approach on how to collect, process and analyse cardiovascular data. In particular, they state that '...although in principle these techniques [frequency domain analysis via Fast Fourier Transform algorithms] have been shown to be powerful tools for characterisation of various complex systems, no major breakthrough has yet been achieved by their application to biomedical data including heart rate variability analysis. It is possible that integral complexity measures are not adequate to analyse biological systems and thus, are too insensitive to detect the non-linear perturbations of R-R interval which would be of physiological or practical importance' (Malik et al., 1996, p. 363). The authors therefore encourage new differential methods to analyse heart rate variability, such as the application of the (multiscale) sample entropy. Indeed, the sample entropy is a powerful tool to understand the complexity of a system, however, its approach to analyse heart rate variability in performance science is yet to be studied (Malik et al., 1996). Based on these recommendations, I apply and compare both the frequency domain analysis and the (multiscale) sample entropy in order to evaluate their application and feasibility in performance science.

2.2 Psychological measures

Validity and reliability Psychological measures are nowadays a common method to explore emotional states in specific performance contexts.[9] An example of a powerful tool that addresses emotions are self-reports through means of questionnaires. Questionnaires contain a set of items that are normally rated on a Likert-Scale, with higher ratings indicating a higher tendency of experiencing a specific sensation. However, to assure that the questionnaire provides you with meaningful information, it is important to evaluate its quality through its psychometric properties, including the properties of *validity* and *reliability* (Hale & Astolfi, 2011; Webb, Shavelson, & Haertel, 2006). Validity assesses whether the question-

[9]This was not always the case; before the cognitive revolution in the 50s and due to the emphasis on behaviours, bare interest in assessing subjective experiences was existent. This was particularly dominant for stress related research as a) little knowledge about theoretical concepts on stress was available, b) ethical considerations of applying stress inducing conditions in a laboratory setting were raised. However, due to conceptual theoretical clarifications and progresses in stress related research, researchers have started to develop scales that are able to detect stress-related emotional responses in a wide range of clinical and non-clinical settings.

naire measures what it aims to measure, while the reliability index provides information about the (internal) consistency of the measure (Field, 2008).

For both reliability and validity, several sub-categories exist:

Content validity: Self-evident, content validity assesses whether the questionnaire measures the content that it claims to measure. In doing so, the questionnaire should encompass adequate items that cover the full range of the aimed construct measured and which are not too similar to each other.

Construct validity: Construct validity describes the association between one (or more) constructs in order to explain specific phenomena. Though these constructs are not directly assessable, the construct can be measured by its variables used. Nevertheless, the more complex the construct is (unidimensional versus multidimensional), the more difficult is its definition. Methods that can be used to test the construct validity may be a correlation analysis between the variables (i.e., items) and the construct (i.e., total scores), a correlation analysis of the measurement given to two different groups, or a more advanced factor analysis.

Criterion-related Validity: Criterion validity is assured when the degree of predictability (i.e., predictive validity) is consistent across a variety of different situations and highly correlated with other established measurements, respectively. Another form is the concurrent validity, which assesses the feasibility of one measurement of different length. Concurrent validity further differentiate between convergent and discriminant validity. While former detects the relation of two measurements, latter compares the administered measurement given to different groups.

Test-Retest reliability or *'Stability'*: Test-Retest reliability refers to the requirement that a test given several times to a sample over a certain period of time should generate a similar item score. For instance, an IQ test given twice within two weeks should produce a stable score for both occasions. This consistency can be assessed by the reliability coefficient, ranging from 0 to 1.00, and should ideally be above a correlation *(r)* of .80 (Hale & Astolfi, 2011).

Parallel or equivalent forms reliability: Parallel forms reliability is assured when two questionnaires measuring the same constructs are highly correlated with each other. Both the parallel or equivalent forms reliability and the test-retest reliability measure the degree of consistency; however, the latter does not provide an index across different measurements. An additional form of the parallel or equivalent forms reliability is the delayed parallel or equivalent forms reliability, where two parallel forms are given twice at two different occasions. The index of quality of the delayed parallel or equivalent is taken from the coefficient of stability or equivalent coefficient aforementioned. The degree of reliability is, again, assessed by a reliability coefficient.

Internal-Consistency reliability: While both Test-Retest and parallel forms reliability are sufficient marker of the quality of measurements, they are rather inconvenient to assess. Instead, the majority of research refers to the internal-consistency reliability, in particular the *Cronbach's alpha (α) coefficient* (Cronbach, 2004). Several possibilities are available to compute the internal-consistency reliability, such as by means of the *Split half-reliability*, which is equivalent to the parallel forms reliability and is calculated by splitting one full-length test into halves—X1 and X2—and by estimating a correlation coefficient for both X1 and X2.

Inter-rater reliability: The inter-rater reliability evaluates the consistency of a measurement not within but between subjects. This is particular valuable when it comes to performances assessed by several external judgers. Here, the reliability index makes sure that, across all judgers, similar outcomes are achieved.

A method that considers the evaluation of both validity and reliability is factor analyses. Factor analyses are part of the Structural Equation Modelling (SEM) and detect correlations between items (i.e., *multicollinearity*) and between items and their underlying constructs (Field, 2008). They may be carried out exploratory (EFA) or confirmatory (CFA); the former is 'data-driven' and applied if little knowledge about the theory exists. The CFA is theory-driven and feasible for hypothesis testing, such as comparing the factorial structure of a questionnaire. Both encompass two key concepts: the evaluation of the factorial variance and the factorial complexity (Munro, 2001). The factorial variance determines the most optimal factorial structure by assessing the: (1) shared variance between factors; and (2) the variance that is specific to one factor. Factorial complexity represents the correlation between a factor and each *item* (defined by the item loading characteristics). An item is, ideally, reflected by one factor. However, items often show cross-loadings, making a clear cut off between factors difficult. Further indications of the factorial structure are *Eigenvalues* (i.e., preferably above 1, which is above *average variance* of the items) or percentages (e.g., a factor accounted for 34% of the item variance.). To gather information about the Eigenvalue, a *factor rotation*—or geometrical reorientation—must be applied. This can be of orthogonal or oblique nature, both informing about the shared variance between factors, yet with the latter assuming a correlation between factors—increasing the factorial complexity. The factorial structure offers an indication of the validity and reliability and can be assessed by model-of-fit indexes, such as:

- Goodness of Fit-Index (GFI);
- Adjusted Goodness of Fit-Index (AGFI);
- Comparative Goodness of Fit-Index (C[G]FI);
- Chi-squared Test (X^2); or
- Root Mean Square Error of Approximation (RMSEA).

The GFI detects the discrepancy between the expected and the actual outcome of the factorial structure (ideally r>.9); the AGFI works similarly though is unaffected by latent variables (ideally r>.9); the CFI functions independently of the sample size (ideally r>.9); the X^2 examines the difference between expected and actually observed covariance matrixes (ideally non-significant p<.05); and the RMSEA is a function of the X^2 test and adjusts for small and divergent samples (ideally r<.06). All these indexes allow the comparison of factorial structures, such as a one, two, three or four factor model with factors that are either correlated or uncorrelated to each other, or factor models of first or second order, with the outcome of the first order providing a theoretical ground for the second order (Ree, French, MacLeod, & Locke, 2008).

Methodological consideration and rationale

Performance stress may trigger a variety of emotions, ranging from positive to negative feelings, such as joy and excitement or worry and anxiety. Most research focused on the sensation of anxiety to address performance stress, using for instance the *Music Performance Anxiety Questionnaire* (Cox & Kenardy, 1993), the *Performance Anxiety Inventory* by Nagel (1990) or the recently developed *Music Performance Anxiety Inventory* (Kenny, Davis, & Oates, 2004). The next section reviews the reliability and validity of these questionnaires, followed by the review of the a psychological measures used in stress research, including response-oriented measures and interaction-oriented stress measures, such as the well-established State and Trait Anxiety Inventory by Spielberger et al. (1983), and the COPE by Carver, Scheier, and Weintraub (1989). The section ends with a summary and a justification of the measure chosen for addressing performance stress in this thesis.

2.2.1 Questionnaires used in music performance science

A questionnaire needs to be carefully examined in terms of its reliability, validity and factorial structure. In the musical domain, most questionnaires are adaptions of already established stress inventories (Osborne & Kenny, 2005).[10]

An example of a commonly used questionnaire in performance science is the *Music Performance Anxiety Questionnaire* (Cox & Kenardy, 1993). This questionnaire consists of 20 items and assesses somatic and cognitive symptoms experienced prior to a musical performance. Developed by Cox and Kenardy (1993), they asked thirty-two musicians to complete the Music Performance Anxiety Questionnaire, the State-Trait Anxiety Inventory, trait form (Spielberger et al., 1983) and the Social Phobia and Anxiety Inventory (Turner, Beidel, Dancu, & Stanley, 1989) during a practice setting, a solo setting and a group setting. A subsequently

[10] The Music Performance Anxiety Questionnaire (Cox & Kenardy, 1993), for instance, is based on the Cognitive-Somatic Anxiety Questionnaire (Schwartz, Davidson, & Goleman, 1978), while the Performance Anxiety Inventory (Nagel, 1990) is a modified version of the Test Anxiety Inventory based on Spielberger (1980).

carried out correlation analysis showed a non-significant relationship between these inventories during practice (r=.13; n.s.), while a significant association was obtained between both the solo setting (r=.59, p<.001) and the group setting (r=.35, p<.05).

Another questionnaire that has been frequently administered to assess performance stress in musicians is the *Performance Anxiety Inventory* by Nagel (1990). This measure is based on the Test Anxiety Inventory (Spielberger, 1980), consists of 20 items and assesses cognitive, behavioural and physiological symptoms experienced prior to a musical performance. Results could demonstrate that the questionnaire exhibit an internal consistency of .89; however, the outcome was only based on a sample of 22 students, and no other psychometric properties were considered.

Initially developed in sport psychology, the *Competitive State Anxiety Inventory-Revised* (Martens et al., 1990) evaluates the psychological and physiological demands of competition in athletes (i.e., assesses how athletes perceive performing under pressure). The measure was adapted from the well-established State and Trait Anxiety Inventory by Spielberger et al. (1970), and was developed with the intention to assess the multidimensionality aspects of performance pressure, including cognitive and somatic anxiety, as well as of the confidence to perform.[11]

To this end, Martens et al. (1990) generated a 27-item measurement, which reflects somatic and cognitive symptoms of performance stress, as well as self-confidence on a 4-point Likert Scale (1='Not at all' to 4= 'Very much so'). Each sub scale contains nine items and involves statements such as 'I am concerned about choking under pressure,' 'I feel nervous' or 'I feel tense in my stomach,' while item samples for evaluating self-confidence were represented by comments including 'I feel at ease' or 'I am confident I can meet the challenge.'

In the musical domain, the Competitive State Anxiety Inventory-Revised has thus far only applied in a handful of studies. For instance, Yoshie, Shigemasu, Kudo, and Ohtsuki (2009)

[11] The authors characterised performance stress as '... the process that involves the perception of a substantial imbalance between environmental demand and response capabilities under conditions in which a failure to meet demands is perceives as having important consequences and is respond to with increased levels of cognitive and somatic state anxiety' (Martens et al., 1990, p. 10).

used the Competitive State Anxiety Inventory-Revised to test whether self-confidence is positively correlated with performance quality, and whether the direction of the cognitive and somatic sub scale positively predicts performance quality. For this, they asked 51 pianists to fill in the State Anxiety Inventory (Spielberger et al., 1983) and the Competitive State Anxiety Inventory-Revised 30 minutes prior to a performance, and let musicians rate their performance quality in terms of articulation, tempo, rhythm, technique, dynamic, phrasing, expressiveness, tone quality, tone accuracy, and organisation. The performance quality rating was based on a 10-point Likert Scale (-5='Much worse' to +5='Much better'), with the midpoint '0' suggesting that the performance during the test setting was as good as their perceived best performance. The authors also administered the The Music Performance Anxiety Questionnaire as a post-performance questionnaire, in where they asked the musicians how they felt during the performance (i.e., retrospective analysis). The results showed a significant positive correlation between the sub scale of the Competitive State Anxiety Inventory-Revised and the State Anxiety Inventory and a significant negative correlation between the State Anxiety Inventory and self-confidence. Self-confidence was furthermore strongly positively correlated with performance quality, suggesting that musicians' level of confidence shapes the success of a musicians' career (McPherson & McCormick, 2006). In terms of the Competitive State Anxiety Inventory-Revised and its internal consistency, the sub scale of somatic anxiety intensity exhibited a Cronbach's α of .85, and the sub scale somatic anxiety direction displayed a consistency of .86. For cognitive anxiety intensity, cognitive anxiety direction and self-confidence, the internal consistency was .83, .78, and .89, respectively. In terms of the construct validity, the correlation analysis between the Competitive State Anxiety Inventory-Revised and the the Music Performance Anxiety Questionnaire showed a significant positive correlation with the sub scale of cognitive and somatic anxiety intensity, and a significant negative correlation between the Music Performance Anxiety Questionnaire and the sub scale self-confidence. Based on this outcome, the authors conclude that '...sport and music performance share some similarities in the anxiety-performance relationship, showing that musicians can benefit, at least partially, from a vast amount of knowledge of anxiety coping strategies accumulated and polished in sport psychology research' (Yoshie, Shigemasu, et al., 2009, p. 74).

A more recently validated musical performance anxiety questionnaire stems from Kenny et al. (2004), namely the *Music Performance Anxiety Inventory* and the *Music Performance Anxiety Inventory for Adolescents*. Both are based on Barlow's (2000) emotion based theory (for more details, Chapter 1) and consider cognitive, behavioural and physiological symptoms, aspects of general and specific psychological vulnerabilities (e.g., parental empathy), as well as anxious propositions (e.g., negative affect, uncontrollability: for more details, see Chapter 2). To evaluate its psychometric properties, they asked thirty-two choir singers to fill out the State and Trait Anxiety Inventory (Spielberger et al., 1983), a modified version of the Music Performance Anxiety Questionnaire (Cox & Kenardy, 1993) and the Music Performance Anxiety Inventory (Kenny et al., 2004). The results demonstrated a Cronbach's α of .94 and an item-total correlation between .34-.89. A subsequent comparison with other inventories showed that the State and Trait Anxiety Inventory and the Music Performance Anxiety Questionnaire (Cox & Kenardy, 1993) accounted for almost 86% of the Music Performance Anxiety Inventory's variance. Overall, Kenny detected three main factors based on her inventory: the first factor accounted for 43% and was labeled as *somatic and cognitive features* while the second factor—identified as *performance context*—was explained by 6% of the variance. The third factor, *performance evaluation*, explained 3%.

To conclude, the questionnaires above have experienced great use in the music domain and can be found in numerous studies addressing performance stress or performance anxiety (for more details, see Chapter 2). However, apart from the K-MPAI, which specifically assesses the state and trait characteristics of performance stress, they do not show sufficient psychometric properties to allow scientifically strong applications. For these reasons, I have decided to employ the State and Trait Anxiety Inventory developed by Spielberger et al. (1983), a widely used questionnaire that has been used in both clinical and non-clinical research studies across a variety of different domains, including military, medicine and psychology. The next section is dedicated to the evaluation of the State and Trait Anxiety Inventory, including its development, psychometric properties and current limitations, before providing a justification as to why I used this inventory in my thesis studies.

2.2.2 Questionnaires used in stress research

Based on decades of stress related research, there are several established questionnaires that fulfil the necessary psychometric properties mentioned above. Again, the main aim of questionnaires in stress research is to capture emotional states induced by specific stimuli or circumstances (i.e., response-oriented measures). These emotional states are understood as individual processes and depended on one's appraisal and coping abilities (i.e., interaction-oriented stress measures). As mentioned in Chapter 1, the response-oriented theories define the response to the environment as the main drive of experiencing stress while the interactional theories emphasis the person (appraisal, coping) as a mediator between the stimulus (and the stimulus characteristics of the environment) and the patterns of response they trigger.

Many questionnaires have been developed in consideration of these aspects and aim to combine introspective reports on psychological, physiological and behavioural signs. The following section offers an overview of the most commonly administered questionnaires in stress-related research, before scrutinising the feasibility of the State and Trait Anxiety Inventory by Spielberger et al. (1983) to assess (music) performance stress.

Response-oriented measures

Depression Anxiety Stress Scale The Depression Anxiety Stress Scale consists of 42 items that aims to assess negative emotional states of depression, anxiety, and stress. The development of this questionnaire has arisen from the lack of defining and understanding the emotional states represented by each of the above stated constructs. Each scale encompasses 14 items that are answered on a 4-point Likert Scale (0 = 'Did not apply to me at all' to 3 = 'Applied to me very much, or most of the time') and are referred to emotional symptoms experiences over the past week (Lovibond & Lovibond, 1995). The summative score indicates the severity and frequency of the emotional states. A short version, the Depression Anxiety Stress Scale-21, is also available, including 7 items per scale. Each scale assesses different emotional contents, such as the ability to become interested, lack of motivation (Depression), the degree of worry, apprehension (Anxiety), experience of physiological symptoms (e.g., dry mouth, dizziness), or the ability to relax as well as tolerance towards interruptions (Stress). The Depression Anxiety Stress Scale can be administrated individually or in groups, in non-clinical, but also clinical assessments, and offers a dimensional rather than categorical classification with regards to the severity of each construct. Application can be found in paper-pencil form. Psychometric properties are provided for non-clinical samples by Lovibond and Lovibond (1995), assessing the Depression Anxiety Stress Scale and Beck Anxiety Inventory as well as Beck Depression Inventory (Beck & Steer, 1993; Beck, A., & Garbin, 1988) in 717 undergraduate psychology students. Internal consistency (coefficient alpha) for each scale was 0.91 (Depression), 0.84 (Anxiety) and 0.90 (Stress). Data treatment included a principal component and confirmatory factor analyses. Former led to three factors, accountable for 41.3% or the item variance. Items received mediocre to high loadings within each factors, but were low for the others. The oblique rotation exhibited three correlated factors Depression-Anxiety r= 0.42; Anxiety-Stress r= 0.46; and Depression-Stress r= 0.39. The CFA (one factor model) yielded an adjusted GFI of .60, with an increase of 0.14 when a two factor-model was applied (Anxiety versus Depression). A further three-factor model, considering Anxiety, Stress and Depression, resulted in phi coefficients of 0.61 (Depression-Anxiety), 0.76 (Anxiety-Stress), and 0.62 (Depression-Stress) and a GFI of .76. This was also backed up by a three-factor exploratory factor analysis, using maximum likelihood as reference point. Results showed the lowest value for the three-factor solution ($X^2_{(738)}$=3025, p>.05). A further second-order factor analysis, including a common factor to allow to influence all three scales, but not each other, replicated an identical fit and item loadings ($X^2_{(816)}$= 3559, p>.05; adjusted goodness of fit=0.76), exhibiting gamma coefficients of 0.71 (Depression), 0.86 (Anxiety), and 0.88 (Stress). Overall, the growing body of studies in stress research show that the DASS-21 exhibits greater discriminant validity than other commonly used measures, including the Beck Depression Inventory and the Beck Anxiety Inventory, suggesting that this inventory is able to successfully discriminate between stress, anxiety and depression (Page, Hooke, & Morrison, 2007).

Symptom Checklist-90-Revised The Symptom Checklist-90-Revised (Derogatis, 1983) is a questionnaire that includes 90 items, ranging from 6-13 items per sub scale. Sub scales are referred to somatization (12 items), obsessive-compulsive (10 items), depression (13 items), anxiety (10 items), hostility (6 items), phobic anxiety (7 items), paranoid ideation (6 items), psychoticism (10 items), interpersonal sensitivity (9 items), as well as 7 additional items about perturbations in sleep or appetite patterns. All items are answered on a 5-point Likert Scale (from 0='Not at all' to 4='Extremely') and ask about symptoms experienced over the last seven days.

The analysis results in three global indices; the global severity index, the positive symptom distress index, and the positive symptom total. The global severity index is drawn from the average mean of all 90 items, the positive symptom distress index refer to the average score above zero and the positive symptom total which shows the amount of items scored above zero (Derogatis, 1983). While the global severity index indicated the level of 'disorder,' the positive symptom distress index indicates the degree of intensity of item responses (e.g., augmenting versus attenuating symptoms). The inventory works self-administered and can be done by paper and pencil, audiocassette or online. The time of administration takes about 10-15 minutes and scores are reported in a or normalized T scores (Derogatis & Savitz, 2000). One of a recent study investigating psychometric properties stems from Prinz et al. (2013), asking 2,727 clinical patients to fill in the Symptom Checklist-90-Revised and the Beck Depression Inventory (Beck & Steer, 1993). Assessments included Cronbach's α, the pearson product-moment correlation, as well as a confirmatory factor analysis, evaluating among others indexes such as the RMSEA and the CFI. Results showed sufficient internal consistency between the Symptom Checklist-90-Revised and its sub scales, demonstrating a Cronbach's α of 0.87 for anxiety and .87 for Depression. In contrast, the factorial validity was slightly below the required threshold, with 0.56 for the RSMEA (cut off <.06) and .74 for the CFI (cut off >.95). The pearson product-moment correlation between the Symptom Checklist-90-Revised and Beck's Depression inventory was significant with r=.80 for the Symptom Checklist-90-Revised Anxiety sub scale and r=.61 for the Anxiety sub scale. These results are in concordance with previously published studies (Schmitz et al., 2000), which recommend that the inventory—as well as the abbreviated form—is a sufficient instrument to assess the state of physiological and psychological wellbeing.

Beck Anxiety Inventory The Beck Anxiety Inventory is a quick and easy Inventory focussing somatic symptoms in order to discriminate between anxiety and depression. The 21 symptoms assessed include items, such as the experience of nervousness, inability to relax, experienced over the last seven days and are rated on a 4-point Likert scale (0='Not at all' to 3='Severely'). It is a paper pencil questionnaire, takes approximately 5-10 minutes and can be purchased from Pearson Assessment (Julian, 2011). The results are calculated by summing the scores, with higher values indicating a greater severity of anxiety. In terms of psychometric properties, the Beck Anxiety Inventory exhibits sufficient construct validity by showing a correlation of .47-.51 with the State and Trait Anxiety Inventory (Spielberger et al., 1983) and .81 with the Symptom Checklist-90-Revised (Derogatis, 1983). The internal consistency ranges from .90-0.94 and has been tested on a wide range of different populations (Osman, Kopper, Varrios, Osman, & Wade, 1997) and is sensitive to change (Julian, 2011). Limitations of the Beck Anxiety Inventory can be found in the comparatively restricted scope of symptoms assessed as well as its overlap with Depression Inventories. Furthermore, the Beck Anxiety Inventory does not exclusively evaluate symptoms of anxiety, but also worry and rumination, making an adequate assessment of anxiety difficult.

State-Trait Inventory for Cognitive and Somatic Anxiety Inventory A relatively new inventory that evaluates the physiological responses to stress is the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA: Ree et al., 2008). The inventory encompasses 21 items rated on a 4-point Likert Scale (1='Not at all' to 4='Very much so') and with higher scores indicating a greater degree of anxiety. Compared to the State and Trait Inventory, the STICSA does not differentiate between 'anxiety-present' and 'anxiety-absent' items rather than between cognitive and somatic symptoms exclusive to anxiety (for more details, see Chapter 2). The STICSA was, contrarily to other anxiety measures, not developed from preexisting measures but from clinical (research) psychologists and graduate students experienced in the field of performance stress research. Based on 113 initial items, 62 items were selected to represent either somatic or cognitive state and trait anxiety symptoms. These were then administered in 576 participants of different economic and cultural background, leading to a final set of 10 cognitive and 11 somatic items. In terms of its psychometric properties, for both scales a superior structure based on the correlated two-factor model was detected. For the trait anxiety scale, results showed a GFI of .96, a CFI of .98, and a RMSEA of .053. Total scores exhibited an unshared item variance of 56% for both cognitive and somatic factors and an internal consistency of .87 for the cognitive factor and .84 for the somatic factor. For the state anxiety scale, results showed a GFI of .97, a CFI of .99, and a RMSEA of .051. Total scores showed an unshared item variance of 47% for both cognitive and somatic factors and internal consistency coefficient was .97. Grös, Simms, Antony, and McCabe (2007) replicated Ree's et al. study by asking 567 psychiatric patients to fill out the STICSA, the State and Trait Anxiety Inventory (Spielberger et al., 1983), the Depression Anxiety Stress Scale-Depression as well as Depression Anxiety Stress Scale-Anxiety sub scale (Lovibond & Lovibond, 1995). A second sample, consisting of 311 psychology students completed the STICSA only. Data treatment included: a one-factor model; two two-factor models (cognitive or the somatic factor versus state or trait factor); and a four-factor model (where state cognitive/somatic as well as trait cognitive/somatic factors were modelled directly). Model of fit indexes were based on the CFI and the RMSEA. The four-factor model yielded an excellent fit across all features, supporting the state-trait and cognitive-somatic differentiation (CFI=.92-.95; RMSEA=.04). For the psychiatric group, high internal consistency coefficients for cognitive and somatic sub scales (.88 and .87, for STICSA trait and state measures, respectively) were detected. The inter-item correlations ranged between r=.41 (somatic) and r=.46 (cognitive) for the STICSA-State scale and between r=.38 (somatic) and r=.44 (cognitive) for the STICSA-Trait scale. A similar powerful outcome was found in the non-clinical sample. In terms of the convergent and discriminant validity, the Trait Inventory for Cognitive and Somatic Anxiety was more correlated with the Trait Anxiety Inventory (Spielberger et al., 1983), while the STICSA-State scale showed stronger correlation with the State Anxiety Inventory (Spielberger et al., 1983). In addition, the State-Trait

Inventory for Cognitive and Somatic Anxiety was stronger correlated with the Depression Anxiety Stress Scale-Anxiety sub scale, while the Trait Anxiety Inventory (Spielberger et al., 1983) exhibited a stronger correlation with the Depression Anxiety Stress Scale-Depression sub scale (Lovibond & Lovibond, 1995).

The State and Trait Anxiety Inventory, trait form and state form The State and Trait Anxiety Inventory by Spielberger et al. (1970) has been translated into over 48 languages and applied in a wide range of different domains, successfully assessing medical disorders, general psychological processes such as attention, memory and learning, experimental and clinical studies. It can be completed in less than 10 minutes and measures the participants' predisposition to being anxious (trait anxiety), as well as the level of anxiety at a given point in time (state anxiety). It contains 20 'anxiety present' and 'anxiety absent' items ('I feel upset' versus 'I am happy'), answered on a 4-point Likert Scale (1='Almost Never/Not at all' to 4='Almost Always/Very much so'), and with higher scores reflecting higher levels of worry and tension (Spielberger et al., 1983).

The main intention is to provide a relatively briefly conductible self-report scale of state and trait anxiety. Both anxiety scales are aimed to go hand in hand; individuals showing a higher score in trait anxiety should also exhibit a higher score in state anxiety. The State and Trait Anxiety Inventory has been a sufficient instrument to measure anxiety (Barnes, Harp, & Jung, 2002), and show moderate to excellent reliability (Cronbach's α>0.86), re-test reliability (α>0.65) and validity across various fields of research.[12] A further reason for its feasibility is its level of simplicity. It can be completed in less than 10 minutes and offers a

[12]Barnes et al. (2002) assessed the internal and ret-test consistency as well as validity of the State and Trait Anxiety Inventory in over 816 studies published between the year 1990 and 2000. For this, Barnes et al. split studies into two publication periods, namely between the year 1990-1994 and 1995-2000. The review consisted of specific criteria, namely studies that assessed its psychometric properties, studies that refereed to other studies in order to justify its feasibility and studies that ignored the assessment of psychometric properties. Barnes et al. further differentiated studies in terms of medical versus non-medical studies, including low- versus high-stress related research (context), the participants' age, design of the study, as well as type of reliability calculated (e.g., internal consistency versus retest-reliability). The findings show that non-medical studies increased their report of reliability coefficients from 6%-10% and were—compared to medical studies—more likely to calculate the psychometric properties from the collected set of data. Medical studies showed a similar trend yet did altogether not provide descriptive statistics. In both cases—medical and non-medical studies—the retest reliability coefficient was more often reported for the Trait Anxiety Inventory than for the State Anxiety Inventory.

strong standardisation sample for comparison.

In terms of its factorial structure, the State and Trait Anxiety Inventory has been claimed to be a multidimensional measure based on a two-correlated method factor model, one labelled as anxiety present (non reversed coded items) and the other anxiety absent factor (reverse-coded items: Lim & Kwon, 2007; Spielberger et al., 1983; Spielberger & Sydeman, 1994). Recent studies, could show a more diverse picture, in particular when the State and Trait Anxiety Inventory was administered alongside other anxiety and depression inventories.

Bieling, Antony, and Swinson (1998), for instance, compared the State and Trait Anxiety Inventory-trait form with measures such as the Beck Depression Inventory (Beck et al., 1988), the Beck Anxiety Inventory (Beck & Steer, 1993) or the Depression Anxiety Stress Scale (Lovibond & Lovibond, 1995). The results showed that based on a sample of 212 patients suffering from various anxiety disorders, the factorial structure that was best presented was the hierarchical model with two lower and one higher order factors—the first two labelled as State and Trait Anxiety Inventory-Depression (STAI-D; 13 items) and State and Trait Anxiety Inventory-Anxiety (STAI-A; 7 items) and the higher factor as negative affect (GFI=.84, AGFI=.80, RMSR=.06). The internal consistency was .88 for the factor depression and .78 for the factor anxiety. A strong correlation was observed between the STAI-A, the Beck Anxiety Inventory and the Depression Anxiety Stress Scale-Anxiety sub scale and the STAI-D with the Beck Depression Inventory and the Depression Anxiety Stress Scale-Depression sub scale, respectively.

Vigneau and Cormier (2008) investigated the factorial structure of both the State and Trait Anxiety Inventory-trait form and the State and Trait Anxiety Inventory-trait form-state form. Several confirmatory factor analyses were carried out based on three samples (n=500-888/group), showing that the two-construct (state versus trait), two-method model (negative versus positive polarized items) revealed the best model-of-fit, accounting for 39%-47% of the item variance—with small variations between each sample (GFI between .82-.85, a CFI between .84-.88, and a RMSEA between .058-.059: Vigneau & Cormier, 2008).

Bados et al. (2010) evaluated the factorial structure of the State and Trait Anxiety Inventory-trait form proposed by Spielberger et al. (1983), Bieling et al. (1998) and Vigneau and Cormier (2008). In addition, they applied a bifactor model, facilitating an easier interpretation compared to general/second-order factor models, especially when comparing different samples (Balsamo et al., 2013)[13]. The model was defined by two specific factors (anxiety and depression, supposedly), one general factor (negative affect, supposedly), while the calculation of items loadings were based on a first order (i.e., all items contribute to the total score: Bados et al., 2010). The results showed a superior model-of-fit for the bifactor model (GFI=.89, CFI=.92, RMSEA=.73), which was then compared with other anxiety and depression measures, such as the Beck Anxiety Inventory, Beck Depression Inventory, the Symptom Checklist-90-Revised.

Table 2.5: Correlation between State and Trait Anxiety Inventory (STAI-Y2: trait form), and other anxiety and depression measures based on Bados et al. (2010), p. 565.

Questionnaire	*STAI-Y2: Depression*	*STAI-Y2: Anxiety*	*STAI-Y2: Total*	*STAI-Y2: Positive Polarity*	*STAI-Y2: Negative Polarity*
Beck Depression Inventory	.70	.61	.73	.70	.65
Beck Anxiety Inventory	.54	.53	.58	.54	.53
Z statistic	**4.75**	**2.28**	**4.51**	**4.71**	**3.39**
Depression Anxiety Stress Scale-21: Depression	.61	.49	.62	.58	.57
Depression Anxiety Stress Scale-21: Anxiety	.42	.43	.46	.45	.41
Z statistic	**3.95**	**1.03**	**3.32**	**2.66**	**3.20**
Symptom Checklist-90-Revised: Depression	.70	.67	.75	.74	.66
Symptom Checklist-90-Revised:Anxiety	.55	.58	.61	.58	.55
Z statistic	**4.68**	**2.64**	**4.67**	**4.97**	**3.14**

Balsamo et al. (2013) re-assessed all proposed factor models on a sample of 1,124 psychiatric outpatients and 877 healthy subjects and administered the State and Trait Anxiety Inventory-trait form alongside other anxiety and depression measures, such as the BAI and the BDI-II (i.e., a modification of the BDI). Results revealed that for both groups the one-construct, two-methods model as well as the bifactor model represented the best model-of-

[13] A bifactor model is a potential alternative to the second order models when '. . . (a) there is a general factor that is hypothesised to account for the commonality of the items; (b) there are multiple domain specific factors, each of which is hypothesised to account for the unique influence of the specific domain over and above the general factor; and (c) the researcher may be interested in the domain specific factors as well as the common factor that is of focal interest' (Chen, West, & Sousa, 2006, p. 190).

fit (GFI of .93; a CFI of .98, and a RMSEA of .07 and a GFI of .93; a CFI of .98, and a RMSEA of .06, respectively, for the clinical sample; GFI of .90; a CFI of .98, and a RMSEA of .08 and a GFI of .90; a CFI of .98, and a RMSEA of .08, respectively, for the healthy sample). The one-construct, two-methods model as well as the bifactor model also exhibited the best reliability; the one-construct, two-methods model demonstrated an internal consistency of .88 and .89 (positive polarity), as well as .89 and .88 (negative polarity) for the clinical and for non-clinical patients, respectively, while the bifactor model revealed an internal consistency of .91 and .89 for depression and .86 and .87 for anxiety for the clinical sample and for the non-clinical sample, respectively. The one-construct, two-methods model showed stronger correlations between positive/negative polarity and the BDI-II (r=.63-.72; r=.62-.71) than between these two and the BAI (r=.59-.62; r=.40-.45), while results from the bifactor model correlated higher with the BDI-II (r=.67-.75; r=.63-.66) than with the BAI (r=.46-.51; r=.59-.64).

Interaction-oriented stress measures

Interaction-oriented stress measures aim to assess the link between performance stress and coping as coping is a strong mediator between the perception and the actual quality of the musicians' performance (Kenny, 2011). Most musicians apply emotion focused coping strategies rather than problem-focused coping strategies (Wolfe, 1990). Emotion focused coping strategies involve emotional regulation to distract from the stressor, while the problem-focused coping strategies are characterised by active problem solving in order to reduce or diminish the source of stress (for more details, see Chapter 1).

Related studies investigating the impact of stress and coping is the study by Fehm and Schmidt (2006). They asked 74 high school students to not only provide information on detrimental performance stress (expressed through increased performance anxiety), but also to pinpoint short- and long-term coping strategies, situational influences on their performance stress as well as about their level of wish to seek for external help. Results showed that somatic symptoms of performance anxiety occurred most frequently by sweaty palms, whereas cognitive symptoms were expressed by enhanced apprehension about possible mistakes as well as being overcritical of the performance (this was detected by the Music Performance Anxiety Questionnaire: Cox & Kenardy, 1993). Those who aimed for a musical career showed fewer complaints about performance stress than those who didn't have such plans. Situational influences affecting the level of music performance anxiety was dependent on the setting and the status of the audience, with solo performance invoking most fear, followed by orchestra, chamber music and private music lessons. In terms of the audience, students report teachers and professors to be most fearful, mainly with regards to their level of professional knowledge and due to the importance of their judgement. Students' first performance, their frequency of solo performances and their frequency of performance during the last six months was not related to their level of music performance anxiety, a result that was also detected by Rae (2004). Short term coping strategies were mainly reported by behavioural actions, such as food intake, rehearsing of difficult parts or washing hands by half of the sample. Cognitive coping strategies, such as positive thinking were used by 81.2% of the sample, however, despite its usefulness, only applied on rare occasions. Other strategies involved relaxation techniques (18.4%), yet with only 6.8% applying these frequently to always. Long-term strategies were defined by seeking help, relaxation techniques, talking to friends or teachers, however with the last two being used rarely or never. In contrast, practice strategies were reported as the main coping mechanism beneficial towards detrimental performance stress by almost 41%. Suggestions to increase the level of coping ability, students suggested implementing interventions during instrumental lessons, such as by a more supporting atmosphere, the possibility to talk or discuss the issue of performance stress as well as by the providing of more performance opportunities. In addition, courses and intervention outside of the class-room was requested, including relaxation training and specific performance training.

Wesner et al. (1990), for instance, examined aspects of performance related problems, such as distress due to performance anxiety, impairment caused by this performance stress and treatment musicians were seeking to cope with it. The results revealed a significant effect of performance anxiety on perceived distress, concentration and musicians' tendency to avoid performing. Drug abuse was unlikely in both men and women and not perceived as performance quality enhancing; contrary, however, prescribed drugs, such as beta blocker were seen as performance improving. Performance stress and the inability to cope with it is characterised by an increase in somatic symptoms such as dry mouth, trembling, elevated heart rate and shortness of breath.

COPE A questionnaire that has been used in performance science and that gives a strong foundation to evaluate the ability to cope with stress in a flexible manner is the COPE developed by Carver et al. (1989). The COPE is a 53-item 4-point Likert scale (1='I haven't been doing this at all' to 4='I have been doing this a lot') questionnaire and assesses 14 components: Active Coping; Planning; Suppression of Competing Activities; Restraint Coping; Seeking Social Support; Emotional, Positive Reinterpretation and Growth; Acceptance; Turning to Religion; Focus on and Venting of Emotions; Denial; Behavioral Disengagement; Mental Disengagement; and Alcohol/Drug Disengagement.

Active coping is the attempt to remove the source of the stressor by the initiative of the individual (i.e., problem-focused). Planning is the consideration of how to successfully cope with the problem, evaluating efficient strategies, yet without taking a direct action. Planning is similar to problem-focused coping (for more details, see Chapter 1), albeit execution appears during the secondary appraisal, rather than as part of an active coping. Suppression of competing activities involves the attempt to not get distracted and to put other interfering thoughts or activities aside in order to be able to focus on the main problem (i.e., problem-focused). Restraint coping keeps the individual waiting until an appropriate time to act on the problem efficiently (i.e., problem-focused). Seeking social support for instrumental also falls under the classification of problem-focused solving and implied the active engagement with third parties to seek help and advice. A similar variable, the seeking support for emotional reasons, is emotion-focused and emphasis moral support, understanding, and sympathy. Such emotional support seeking may either lead into another problem-focused solving approach or to the mainly dysfunctional approach of, e.g., focusing and venting of emotions, which is the tendency to concentrate on the distressing event and to ventilate those feelings. Other maladaptive problem solving strategies are the behavioural disengagement. The behavioural disengagement reduces the endeavour to actually tackle the problem, and is identified with other concepts, such as helplessness, or self-handicapping, leading to poor coping outcomes. Mental disengagement is a side effect of the behavioural disengagement and reinforces the avoidance to deal with the problem by applying mental distractions, such as daydreaming, escaping through sleep or watching TV. Positive reinterpretation and growth, also classified as positive reappraisal (Lazarus & Folkman, 1984) includes emotion-focused problem solving and emphasis the reduction of distress (e.g., anxiety) rather than to deal with the source of the problem. Denial occurs during the primary appraisal and has been seen as either useful to minimise the stress and to actively engage with the problem or to generate additional problems by ignoring the stressor and, thus, increasing the risk of becoming severe. Acceptance implies two concepts; acceptance of a stressor may occur during the primary appraisal or during the secondary appraisal, which comes alongside the absence of a current coping strategy. Turning to religion is an emotional problem and problem coping strategy that may either add emotional support during the appraisal process or assist as a tactic to actively cope with the stressor. Alcohol/Drug Disengagement involves substance misuse and aids further distraction from the source of the problem.

The COPE was developed with the intention to incorporate the diversity of coping and to overcome the often vague and ambiguous items used in other coping measures, based on empirical assumptions rather than on the consideration of the theoretical aspect of coping. As such, it is an ideal tool to be used for further assessment of performance stress in the music domain. The inventory was first evaluated by Carver et al. (1989), who administered the final set of items—after several re-evaluations—to 978 students and evaluated its factorial structure. The results showed 11 factors that had a greater Eigenvalue than 1 and with each scale showing an internal consistency of above .60.

The COPE was also compared with other measures, such as the Self-esteem Scale (Greenberg et al., 1992) and the State and Trait Anxiety Inventory (Spielberger et al., 1983). Strong significant positive correlations were found between the the Self-esteem Scale and the sub scales active coping, planning, and positive reinterpretation and growth, as well as significant negative correlations for the sub scales focus and ventilations on emotions and behavioural disengagement. For the State and Trait Anxiety Inventory, significant negative correlations were observed for the scales active coping, positive reinterpretation, and significant positive correlations between focus and ventilation of emotions, denial, and behavioural and mental disengagement. A psychometric re-assessment of the COPE stems from Lyne and Roger (Lyne & Roger, 2000), administering the questionnaire to 1395 (return and complete response rate: 539), with almost 90% of the sample being female. The COPE was also given alongside scales, such as the Eysenck Personality Questionnaire (Eysenck & Eysenck, 1964), the Depression Anxiety Stress Scale (Lovibond & Lovibond, 1995) or the Positive and Negative Affect Scale (Watson, Clark, & Tellegen, 1988). Data treatment included an exploratory factor analysis, and final results showed a three-factor solution, labelled as Rational or Active Coping, expressing feelings and seeking emotional support, Avoidance Coping or Helplessness. Litman (2006) examined the factorial structure of the COPE by asking 230 students to fill in the COPE, the International Personality Item Pool Extraversion Scale (Goldberg, 1999), and the Trait scales of the State Trait Personality Inventory (Spielberger, 1979). A factor analysis (oblique rotation) resulted in a four-factor solution, accounting for approximately 80% of the variance. Factor 1 was labeled as problem-focused coping strategies (61%), factor II as avoidance coping behaviour (46%), factor III was determined as socially supported coping (62%) and factor IV (38%) was characterised as emotion-focused strategies. Correlations with other measures revealed low (and negative) correlations between trait anxiety and problem-focused coping strategies, as well as social support, and highest relationships with avoidance coping strategies, such as behavioural and mental disengagement. The trait Extraversion showed higher correlations with strategies, such as planning and active coping, as well as instrumental social support, and lower correlations with behavioural disengagement, denial, as well as emotional restraint. In a follow up study, they asked 357 students to complete the COPE, the Trait Anxiety Inventory (Spielberger, 1979) and the Values and Action Inventory of Strengths (Peterson & Seligman, 2004). This time an exploratory factor analysis suggested a three-factor solution, accounting for 70% of the variance. All three factors exhibited similar item and scale loadings than in the first study; with the first and the third showing greater correlation (*r*=.58) than the second with the first (*r*=.18) and the third (*r*=.16), demonstrating that self-sufficient and socially supported strategies revealed stronger association to one another than the avoidant coping strategy. A comparison with the other measures showed a similar trend for the anxiety measure; significant negative relationships were detected between anxiety and planning, active coping and positive reinterpretation and growth, and strongest positive correlations with avoidant coping strategies, such as behavioural disengagement and denial. The Values and Action Inventory of Strengths, measuring positive traits was significantly positive correlated with each sub scale of self-sufficient strategies (e.g., planning, active coping) and, as expected, significantly negative correlated with avoidant coping behaviour, such as behavioural disengagement.

Overall, the COPE seems adequate for identifying the coping strategies applied in musicians during the experience of performance stress, and adds some valuable information with regards to the interaction-oriented stress theories (for more details, see Chapter 1).

Health-Promoting Lifestyle Profile II Another questionnaire that has been used in stress research and which has also found some application in performance science is the Health-Promoting Lifestyle Profile II by Walker, Sechrist, and Pender (1987). The Inventory is an indirect measure of coping abilities and measures health-promoting behaviour based on self-initiated actions and perceptions and evaluates features such as spiritual growth, interpersonal relations, nutrition or physical activity. It has been developed by Walker et al. (1987), administering a 100-items dichotomous (yes/no) scale from a checklist used in clinical nursing school. Results based in an factor analysis showed that the scale contains six dimensions, explaining 47.1% of the total variance. The overall internal consistency of the inventory was .94, and the sub scale consistency ranged between .79-87., while the criterion validity (measured against a perceived health status and quality of life) was between .26-.49, respectively. The test-retest comparison demonstrated a stable Cronbach's α of .89. Other studies that tested the inventories in terms of its factorial structure stems from Pinar, Celik, and Bahcecik (2009). Based on a sample of 920 students, internal consistency, item-total correlation and test-retest stability (2 weeks apart) was calculated. Goodness-of-fit indexes were: the CFA; the CFI; the (adjusted) GFI; and the RMSEA. In addition, cross-scale correlations were obtained for each sub scale. Results show an internal consistency coefficient of .92 for the whole inventory, while values for the sub scales (N, PA, HR, SM, IR, and SG) ranged between .73-.83, respectively. Item-total correlation was exhibited above the required .20 threshold; the test-retest reliability coefficient for the whole inventory was .95 and for each sub scale between .73 and .87, respectively. In terms of the construct validity, a first factor analysis revealed a 5-factor solution, explaining 41% of the variance. Two items were deleted due to low factor loadings, leading to an item-correlation above .30 for all items. A subsequent calculation of the Cronbach's α yielded values ranging between .64 and .93 for each factor, while item-total correlations ranged between .20-.69. The first factor included items based on the sub scale SG, IR, and DM; the second factor contained items from the sub scales health responsibility, nutrition, and interpersonal relationship; the third factor represented items from the sub scale PA; the fourth factor contained items of the sub scale SM; and the fifth factor was related to items from the sub scale N. Pinar et al. (2009) furthermore compared their five factor solution against the six factor model proposed by Walker et al. (1987). The subsequently carried out confirmatory factor analysis demonstrated moderate model-of-fit indexes (CFI=.89; GFI=.87; AGFI=.71; RMSEA=.22), while the deletion of 4 items led to a significant improvement (CFI=.96; GFI=.95, AGFI=.88, RMSEA=.04). Cronbach's α for the whole inventory was .91 and ranged between .70 and .83 between sub scales. Furthermore, low correlations between the sub scale IR and PA (r=.20) was observed, while strongest associations were found between the sub scale spiritual growth and interpersonal relationship (r=.88). Last, item-total correlation for the entire inventory ranged between .20 and .65. Another study investigating the psychometric properties of the HPLP II stems from Meihan and Chung-Ngok (2011). Their evaluation included the calculation of its internal consistency and item-total correlation of each sub scale. Their confirmatory factor analysis assessed the initially proposed 6-factor structure, albeit let to the deletion of one item, increasing the Cronbach's α from .71 to .73. The remaining 51 were revalidated, producing an AGFI of .95 and a RMSEA of .001, while correlations between the HPLP II and sub scales ranged between .74 and .87. The internal consistency of the total score was .91 and the sub scales ranged between .81 (SM) and .86 (SM). The authors, furthermore, compared the inventory against the World Health abbreviated Organization's Quality of life assessment (WHOQOL-BREF; Yao, Chung, Yu, and Wang (2002), participants' perceived health status and demographic background. Results showed that the Health-Promoting Lifestyle Profile II correlated significantly (p<.05) with the WHOQOL-BREF and the self-reports given—shown by a positive relation between the financial status of participants and their educational degree. Perez-Fortis, Ulla Diez, and Padilla (2012) administered the inventory in a sample of 1.219 college students, assessed its factor structure (varimax rotation) and compared several them with several confirmatory factor analysis. Goodness-of-fit indexes included the GFI, the adjusted goodness of fit index (AGFI), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA). Due to a too low item-correlation (<.20) two items (N14 and 50) were excluded. The exploratory factor analysis of 50 items led to six factors that accounted for 40% of the variance. After the removal of six further items due to low cross loading difference (<.10), 44 items remained for further analysis. The first factor (PA) was represented by items from the PA, the second factor (SG) by items from the SG and IR; the third factor (IR) by items from spiritual growth as well as health responsibility, while the fourth factor (HR) included items of the HR and the SM. Finally, the fifth factor (SM) included items from both sub scales N and SG. Another CFA compared the new 44-item structure with the previous 52-item inventory. While the initial 52 items revealed a RSMEA, CFI, GCI, and an AGFI of .05, .94, .75, and .73, respectively, the 44-item inventory revealed a RSMEA CFI GCI and an AGFI of .04, .96, .83, and .81. This superior outcome was also reinforced by the increased internal consistency of .87 for the total inventory, and .51 (stress management) and .82 (physical activity) between sub scales.

In performance science, the Health-Promoting Lifestyle Profile II was for instance applied by Ginsborg, Kreutz, Thomas, and Williamon (2009), who assessed musicians' degree of health promoting behaviour, level of self-efficacy, and musculoskeletal health problems and compared them to students of nursing and biomedical science. The results demonstrated that music students are significantly less conscious about their health compared to their counterpart, experiencing lower self-efficacy and higher musculoskeletal health problems. Kreutz, Ginsborg, and Willamon (2008), using the same inventory, demonstrated furthermore a general engagement toward health promoting behaviour, such as nutrition, interpersonal relations, and spiritual growth, albeit such engagement did not include effective physical activity or stress management. As such, the Health-Promoting Lifestyle Profile II may be an ideal tool to address musicians' health promoting behaviour in a rigorous manner.

Summary and approach used in this thesis Questionnaires allow a quick assessment of large samples with relatively little effort. To gather meaningful information, they must, however, fulfil certain psychometric properties, such as a decent validity and reliability (Hale & Astolfi, 2011). A valid questionnaire measures for what it has been designed for (Field, 2008). This sounds rather simple, yet contains many theoretical and practical challenges. A well-validated questionnaire provides a comprehensive and well-thought-through rationale as to why items (or factors) have been chosen; yet, theoretical construct may be complex, contain many features and challenge the identification of an appropriate set of items. A reliable questionnaire demonstrates a sufficient test-retest reliability or internal consistency. High test-retest reliability occurs when the questionnaire produces similar outcomes after having been applied several times, while the internal consistency assesses the degree of regularity between items, but also subjects (split half-reliability versus inter-rater reliability).

For my thesis, I decided to administer the State and Trait Anxiety Inventory, trait and state form, developed by Spielberger et al. (1983). Translated into 48 languages, the State and Trait Anxiety Inventory is completed in less than 10 minutes and measures the participants' predisposition to being anxious (trait anxiety), as well as the level of anxiety at a given point in time (state anxiety). It has been widely tested and is considered as 'established' measure to identify musicians' psychological state. The inventory has, based on a meta-review carried out by Barnes et al. (2002) moderate to excellent reliability (Cronbach's α>.86), re-test reliability (>.65) and validity across various research fields, such as medicine, psychology and sport.

2.2.3 Interviews

Interviews collect contextual and temporal perspectives on a specific topic, with researchers being actively engaged with the situation and the participants (Morgan, 1997; Onwuegbuzie, Leech, & Collins, 2010; Rabiee, 2004). The type of interview used and addressed in this thesis is the focus group interview. The focus group interview is carried out if relatively little knowledge about the topic exists. Ideally, it should take place in a comfortable and 'non-threatening' environment and be supported by a moderator, who has an in-depth understanding of the content, a high degree of personal engagement and the skill to balance the group dynamic (Courage & Baxter, 2005).[14] Alongside a moderator assists note-takers, videographers, or observers. Note-takers keep track on details, draw lines between comments and refer them back to previous observations. They also prevent the group from repetitions of similar content. Videographers record the interview and observers evaluate potential discrepancies between what has been said or avoided due to e.g., social desirability (Wimmer & Dominick, 1997).

A successful focus group interview is foremost defined by a detailed activity timeline. An activity timeline contains a report of each action, such as introduction, discussion, wrap up procedure and the calculation of its approximate duration. During the introduction, participants are welcomed, asked to take their seats and to eventually fill out paperwork. Subsequently, an explanation of the purpose of the interview and its main ground rules are provided (e.g., confidentiality and free expression and tolerance of opinions). The interview then starts with a broad 'opening-question' in order to get a first impression of the group dynamic and to obtain a rough idea of how the interview might evolve. The interview should appear as loosely structured as possible, allowing conversations of unexpected outcome and interactions between participants rather than between the participant and the moderator.

The structure of a focus group interview is determined by the questions asked; these can be

[14] As such, the moderator secures space for a fruitful discussion, facilitates activity and tolerates and keeps track of comments that might be contradictory to common group opinions. Simultaneously, a successful moderator keeps track on the lists of questions—all of which should preferably be answered within the session held.

structured, semi-structured, or open-ended. Structured interviews (e.g., Yes/No answers) ensure a complete data set, yet also reduce the richness of the data. Open-end interviews (e.g., 'How do you experience. . . ?') enable greater expression of individual opinions on a certain topic; yet they require a time-consuming analysis/interpretation (Wimmer & Dominick, 1997). An alternative to both is semi-structured focus group interview; they allow a greater expression of opinions, while being able to collect the required information. The focus group interview is then transcribed by either members of the research team or external companies for an agreed fee.

The focus group interview is analysed based on a data reduction process and in order to identify overarching themes (Courage & Baxter, 2005). For instance, the more words or phrases are repeated the stronger is the justification to use them as themes. The same accounts for familiar/unfamiliar words (these may encompass the use of 'local' language, adding further meaning to the context), metaphors, analogies and transitions, discovered by pausing, a changed tone of words or interruptions. Similarities and linguistic connectors serve as another indicator by making comparisons across data units, or by looking at single words, such as 'because' (i.e., causal relations), 'if. . . then' (conditional relations), 'is a' (i.e., taxonomic categories), 'before', 'after' (i.e., time-oriented relation). Themes can also be represented by missing data and are defined by what has not been said or avoided. Theory-related material focuses on themes that illuminate questions of theoretical importance.

Themes can be subtle, symbolic or a product of cultural agreement and should be attached with core and peripheral elements that are ordered towards a hierarchical structure and supported by with quotes of the actual data. This is done by methods such as cutting and sorting, word lists and key words in context (KWIC), word occurrence, or meta coding. Cutting and sorting—also called 'Cut and Paste'-method—facilitates the identification of emerging phrases, sentences or exchanges between participants by using a coloured system approach. Categories created either maximise differences or emphasise similarities (Bernard & Ryan, 2010; Robson, 2011). The KWIC is based on simple frequency word counts and helps researchers to get a first idea of relevant themes. Word counts can be illustrated in 'respondent-by-word matrices, scree plots (by having the number of participants on the y-axis and the ‘unique’ words on the x-axis) or similarity matrices. Word-occurrence refers to words that appear most likely linked with related ones. The word ‘crime’, for instance, is often combined with the word ‘violence’, while the word ‘performance’ usually comes alongside ‘nervousness’ or ‘stage fright’. Meta coding examines themes embedded in overarching themes and requires extensive time commitment and experience in qualitative research. To assure reliability, more than one member of the research team should carry it out.

The analysis of focus group interview can also be carried out using computer assisted qualitative data analysis software (CAQDAS). The most common software packages are Verbastat (by SPSS), Ethnograph (by QSR international) or NVivo (by QSR international). Each differs in terms of costs, focus and simplicity; the software package Verbastat or Ethnograph, for instance, is a simple descriptive tool, while NVivo links codes to their potential hierarchies, generating a more advanced theory-building approach (Table 2.6: Duriau & Reger, 2004; Zikmund & Babin, 2010).

Table 2.6: Strengths and weaknesses of the CAQDAS (Duriau & Reger, 2004).

Strengths of CAQDAS	*Weaknesses of CAQDAS*
Manipulation of large data sets	Difficulties in detecting latent content
Organizing, searching, retrieving, and linking data effectively	Difficulties in detecting and analysing colloquially expressed content
Time and cost-effective	Risk of too much reliance on software
Offers increased amount of details, but also data reduction	Risk of losing the overall context
Explicit coding rules, which leads to increased reliability/validity	Great price ranges depending on the software required
Comparability across different texts	
Equally if not more effective than human intervention	
Functions multimedia by means of the possibility to attach graphics, video and audio recordings	

Once the data has been organised and interpreted in relation to the theoretical constructed tested, results have to be written up for potential publications, reports or dissertations (Taylor & Bogdan, 1998). This involves the consideration of several steps: firstly, it is inevitable to inform the reader about methods and analyses used (e.g., structured questions, focus group interview, etc.) in order to allow replication. This also encompasses the number of participants, the setting, and the time and length spent on the data collection. Secondly, it needs to be defined whether the data collection was purely descriptively driven or considered to fill the gaps within a theoretical concept. Consequently, changes in assumptions and perceptions throughout the process of analysis should be provided. Thirdly, data should be reported in a concise and direct way, including quotes, an interpretation, and a conclusion. The overuse of similar quotes should be avoided to reduce the impression of poor data. Quotes should not be changed unless the context does not allow otherwise (should this be the case, parentheses including commas should be incorporated). They should be short and crisp in order to: (1) not lose the reader's attention; and (2) keep a clear line of thoughts. Comments from note takers or observer should not be implemented. Lastly, qualitative data should not be reported in a quantitative way, using words, such as findings, informants, or people instead of including results or participants. Findings should be presented in the first person perspective—they are your findings and your conclusions (Breakwell, 2006). In summary, quotes should be kept as natural as possible and not be overstated. Despite the aim of verifying or falsifying an a priori made assumption, they are not the ground truth. Data represent a perspective of a particular group at a particular time and might not necessarily be applicable to a broader population.

Overall, interviews are conducted to get an in-depth understanding of a population within a certain context and are conducted by either one-to-one or group interviews. Depending on the setting and research objectives, questions may be structured, semi-structured or open-ended. While structured questionnaires determine the choice of answers, semi-structured allows more space for subjective expressions. Open-ended questions offer most meaningful by means of limitless expression. On the downside, such possibility is time consuming, and requires a complex data analysis. This can be partially overcome by qualitative computer software tools, ranging in simplicity and costs, starting from basic word counts to more advanced coding systems. Preferably combined with human evaluation, the data output should be considered in terms of:

- Words (e.g., specific meaning)
- Context (e.g., answer triggered by a question versus a comment)

- Internal consistency (e.g., change of the interpretation of experience)
- Extensiveness and Frequency (e.g., how many participants said what how often, time spend on a specific question)
- Intensity (e.g., emotionally delivered)
- Specificity (e.g., specific versus vague responses) in order to detect the
- Big themes (i.e., ideas).

As such, the researcher detects important parts within the text, develops a categorical system of representative statements, quotes, phrases—all of which aim to facilitate a meaningful interpretation of the data obtained. Conducting interviews, however, also encompass some challenges; firstly, interviews have been criticised for many not foreseeable obstacles, such as the degree of reactivity in participants, the pressure to go through the questioned prepared, or the social norms and adaptions interviewed are exposed to. Secondly, the analysis of qualitative data provides room for subjective interpretations, not necessarily reflecting to true content of the data. To prevent such violation, several assessors are recommended in order to increase the degree of reliability and validity.

Summary and approach used in this thesis Interviews are most suitable for samples ranging from one-to/one interviews to group interviews. Given the nature of the interview setting and the research objectives, questions asked may be structured, semi-structured or open-ended, consequently varying in their degree of complexity. While structured questionnaires require a simple—yes or no—answer, semi-structured allows more space for subjective expressions. Open-ended questions offer the most meaningful interrogation by allowing the interviewed to limitless expression. On the downside, such approach is time-consuming and includes the increased risk of biased analysis. A tool that helps to analyse such complex data is the application of software tools. Such facilitators allow a quick and relatively unbiased data analysis and range from simple word frequency tools to more advanced coding system.

Thus main aim of a FGI is to develop categories of representative statements, quotes and phrases in order to facilitate a meaningful interpretation of the data. The selection of an adequate technique depends on various factors, ranging from the characteristics of the data collected, the skill set of the researcher, as well as the consideration of the amount of labour. Data may include transcriptions, but also video and audio files, varying in time, length and detail. Depending on these, different methodological approaches may be chosen.

The rationale for using a focused group interview to collect qualitative data was to gain a variety of perspectives on the same topic. In this case, the experience and perception of using simulation training. The focus group allows to obtain knowledge of participants' shared understanding of using simulation training, and, if led well by the moderator, provides some meaningful data. It furthermore is well-suited for discussing new a research area and to obtain some preliminary data where little understanding of the topic addressed exists. I used focus group interviews to explore a thematic concept that is not easy to observe and difficult to get access to. It also allows to collect a concentrated set of personal perspectives in a very short amount of time. All these aspects speak for the feasibility of my choice of using focus group interviews.

The data collected in this thesis was based on a semi-structured focus group interview and conducted by the researcher with two observers making notes that were discussed afterwards. The material was transcribed and analysed using NVivo in order to detect the main themes (see Chapter 6). The analysis was next carried out using a Thematic Analysis—a bottom up process that generated meaningful themes from the data.

Thematic analysis helps you to identify, analyse and report themes within a data set. It is based on the fact that the execution of thematic analysis is relatively loosely determined, it is important to provide details of the process and details of analysis as much as possible (Braun & Clarke, 2006). The researcher who conducts a thematic analysis should ideally acknowledge her/his own theoretical position of the research, an outline of what the researcher wants to know. Thematic analysis seeks to describe themes across qualitative data rather than within a data item, such as found in an individual interview (biographical or case-study), and is particularly suited for researcher in their early career in qualitative research.

Thematic analysis may involve a realistic method, which reports experiences, meanings and the reality of participants, or it may involve a constructionist method, which assesses the way how experiences, events or realities are shaped by a wide range of discourses within the society. Thematic works therefore in both way to either reflect reality or to unravel the surface of reality.

Themes of patterns within the data set can be found by means of an inductive 'bottom up' process or through a more theoretical or deductive 'top down' approach. The former is characterised by a strong link with the data that have been collected (e.g., through focus group interviews), and with themes having little connection to the specific questions that participants were asked. Inductive data analysis is a process that is absent of the aim of trying to fit into a pre-existing framework, or the researcher's preconceptions.[15] In contrast, a 'theoretical' thematic analysis is driven and characterised by a theoretical or analytical framework that is of interest for the researcher. This approach is therefore analyst-driven; the description of the data is less rich than for the inductive thematic analysis, yet more detailed in terms of the analysis of the data (Braun & Clarke, 2006). The choice between these two remains to be related to the coding process itself. This may involve the aim to code for a very specific research question (which is related to a more theoretical approach), or the research question evolves through the coding process (which is related to the inductive approach).

Another decision the researcher needs to look at is whether the thematic analysis follows an either semantic or latent approach. Semantic themes, for instance, show results that go beyond of what the participants have said or written. Ideally, the results should display a progression which involved the description of the data; the researcher should be able to provide a content that has been organised and which has specific characteristics, and contains a summary for further interpretation. This allows to theorise the significance of the pat-

[15]This does not mean that the researcher should not be thinking about his/her theoretical commitments.

terns and their broader meaning and conclusions. It also enables the discussion in relation with previous findings within and across research fields. In contrast, the thematic analysis at the latent level aims to identify the *underlying* ideas, assumptions and conceptualisations in order to give the data a particular form and meaning. In doing so, the latent thematic analysis requires an interpretative framework of the development of the themes themselves and results that are not based around descriptions rather than have been theorised already.

In my thesis, I used a bottom-up approach based on a semantic level of thematic analysis. The evaluation of simulation training and musicians' perception of using simulation training is novel in the sense that this is the first study that looks at the benefits of simulation training from a qualitative perspective (for more details, see Chapter 5). In doing so, the thematic analysis allows me to work data-driven and to provide an in-depth analysis of the patterns found within but more importantly across participants.

2.3 Specific research questions and hypotheses

Background and rationale The first attempt to introduce the taxonomy of stress dates back to Selye in the early nineteenth century (Selye, 1936), who defined stress as a 'non-specific' endocrine response. Current stress research explains the phenomenon through the modulation of the autonomic nervous system (ANS) in response to stressors, whereby both the sympathetic (SNS) and parasympathetic nervous system (PNS) are involved with involuntary regulation of key bodily functions, including heart rhythms, respiration and blood pressure (Billman, 2011). When it comes to the biomarkers of stress, the time series of consecutive R-peaks in the Electrocardiogram (ECG), referred to as heart rate variability, have been widely adopted as robust signatures of stress (Thayer & Lane, 2009).

Musical performance is a particularly suitable and fruitful scenario for studying performance stress, in particular heart rate variability reactivity to stress (Williamon, 2004), as the performance is both controllable for researchers and naturalistic for both the musicians and the audience. The stressors in a musical performance are manifold, from bright spotlights, TV cameras and expert audiences, to the fact professional musicians are expected to deliver performances of consistently high quality, whereby in the extreme the quality of a single performance may determine their careers. Performance stress has been shown to occur regardless of age, sex, hours of practice and level of expertise. Even eminent musicians such as the pianist Vladimir Horowitz and the singer Maria Callas were not beyond experiencing it.

While the psychology of musical performance stress is an already maturing area, with several subjective stress assessment methods available, there is, from both the scientific and practical perspective, much scope for the use of modern wearable sensing technologies, as well as methodologies, to provide a quantitative and objective account of performance stress, such as an assessment of the critical timing of stress reactivity.

Considering the existing music research and building on the promising new approaches to analysing physiological responses to stress, the aim of this thesis is to provide further understanding of musicians' cardiovascular reactivity to stressful performance situations. In particular, I sought specifically to examine the degree and timing of peak stress levels in musicians experiencing performance stress.

2.3.1 The aims of this thesis

The aim of this thesis is to address conservatoire musicians' cardiovascular reactivity to stressful performance situations, by asking the following research questions:

- To what extent do physiological and psychological symptoms arise under different performance contexts (e.g., low-stress rehearsal versus high-stress audition)?
- How is stress manifested over time, such as from the pre-performance period to the performance itself?

These two questions are investigated by considering well-established standards in physiological assessments, as well as by comparing them against newer methods as proposed in complexity science (Chapters 3 & 4). In Chapter 3, the physiological response of an expert musician was evaluated in low stress (a rehearsal) and high stress (a recital for 400 people) performance conditions and along a piece of music of varying difficulty. The study aims to answer the question of physiological changes in heart rate variability over time during a low- and high-stress performance, as well as a comparison between the results provided by the frequency domain analysis and the multiscale sample entropy performed in complexity science.

Chapter 4 offers further insights into the degree and peak of cardiovascular reactivity between low- and high-stress performances. Musicians' heart rate variability was monitored during a 5-minute pre-performance period and during a low- and high-stress performance; self-reported anxiety was collected prior to the events. This study was carried out in the hopes to get a better understanding of the importance of the pre-performance period, as well as to test and evaluate the frequency domain analysis and the multiscale sample entropy method in a larger sample.

Subsequent studies examine the impact of training programmes on physiological features, including a qualitative and quantitative validation of simulated musical training environments (Chapters 5, 6 & 7) developed at the Royal College of Music. For the validation, research questions of interest are:

- To what extent do simulated musical performance environments have an impact on musicians physiological and psychological responses?
- Moreover, to what extent are they comparable to a real performance setting?

In Chapter 5, advanced violin students were recruited to perform in two simulations: a solo recital with a small virtual audience and an audition situation with three 'expert' virtual judges. Each simulation contained back-stage and on-stage areas, life-sized interactive virtual observers, and pre- and post-performance protocols designed to match those found at leading international performance venues. Participants completed a questionnaire on their experiences of using the simulations. The study was conducted to explore the face validity of the simulation training, expressed in physiological and psychological metrics, including a comparison of musicians' heart rate variability and feelings of anxiety before and during simulated performance and real performance.

In Chapter 6, conservatoire students performed in two simulations: a recital with a virtual audience and an audition with virtual judges. Qualitative data were collected through a focus group interview and written reflective commentaries. The aim of this study was to find the answer as to how musicians would use simulation training if it was part of their everyday practice-curriculum.

Finally, in Chapter 7, data from twelve musicians who performed twice in the simulated environment are reported. The heart rate variability was monitored throughout the performance including a 5-minute pre-performance period while self-reported anxiety was assessed before and after. The heart rate variability was examined in terms of standard frequency and multiscale sample entropy methods. This study was aimed to understand the impact of positive versus negative feedback on stress responses, in particular we sought to test the hypothesis that feedback of positive valence has a significantly different impact on these responses than feedback of negative valence.

Chapter 8 offers a discussion based on the outcomes of studies carried out, as well as future implications for research in the musical domain.

3 | Changes in heart rate variability during musical performance: A case study

3.1 Introduction

Performing music in public requires the management of intense physical and mental demands. How musicians perceive and respond to these demands, and deliver high quality performances consistently under pressure, can determine not only the success of single events but also the path and length of their careers (Kenny, 2011; Williamon, 2004).

In this respect, musicians are not unlike elite performers in other domains. Under intense stress, physiological and psychological responses such as heart rate and level of state anxiety are markedly increased for both those who must work hard physically, such as athletes (Bricout, DeChenaud, & Favre-Juvin, 2010), as well as those whose work requires mental exertion, such as surgeons (Arora et al., 2010) and chess grandmasters (Schwarz, Schächinger, Adler, & Goetz, 2003). While the analysis of physiological responses is well explored in sports science and in many clinical fields, studies in music, particularly those examining stress in real-world contexts and at the highest of international levels, are rare.

Stress is managed by the autonomic nervous system (ANS). In particular, a reaction to stress can be characterised by the interactions between two ANS components: the parasympathetic and sympathetic nervous systems (Berntson & Cacioppo, 2004: for more details, see Chapter 2). Stress often causes a decrease in the mean R-R (increased heart rate) in healthy individuals, with the opposite effect in chronically stressed individuals (Schubert et al., 2009), while in the case of standard deviation, certain studies have found that it fails to identify the effects of mentally stressed individuals stress on heart rate variability (Taelman, Vandeput, Spaepen, & Van Huffel, 2009). To put this into context, Schubert et al. (2009) examined the short-term stress effects on heart rate variability using complexity domain measures (phase domain measures) and frequency domain analysis in fifty (healthy) participants. The short-term effects of stress were investigated through a short speech task and participants' changes in cardiac output were measures through monitoring their ECG (including breathing) throughout. The results showed a significant increase in in mean heart rate and standard deviation in R-R fluctuations, LF power and decreased HF power for the speech task, while the LF/HF ratio and the respiratory sinus arrhythmia did not change. Based on these observation, the authors conclude that the stress condition reflect a lowered functionality of the cardiovascular activity and confirm the importance of the complexity metrics in modern stress research on heart rate variability. Taelman et al. (2009) addressed the problem to analyse and identify period of stress by recording alterations in heart rate and heart rate variability by means of exposing 28 participants to two conditions: a task with and without a mental stressor. For this, participants were first provided with relaxing pictures in order to make them feel calm and then required to execute a mental task. The heart rate variability was analysed in terms of time or frequency domain analysis, and metrics of interest were: mean and standard deviation (SD) of R-R, mean and SD of heart rate, root mean square of SD, NN50 (number of consecutive R-R intervals that differ more than 50 ms) and pNN50 (proportion of NN50). Frequently used spectral components extracted included the very low frequency bands (VLF: $0 - 0.04\,\text{Hz}$), low frequency bands (LF: $0.04 - 0.15\,\text{Hz}$) and high frequency bands (HF: $0.15 - 0.4\,\text{Hz}$) and the ratio of LF/HF. The results revealed a significantly lower mean R-R during the mental task and compared to the resting state. The pNN50 was significantly higher in the relaxed condition than during the exposure to the mental task, while the standard deviation did not vary significantly between the two performance tasks. For the results of the frequency domain analysis, all frequency components were not significantly different between conditions; only the LF/HF exhibited a slightly higher power during the mental task (although non-significantly so).

In recent years, studies of heart rate variability have focused on its low frequency (LF) and high frequency (HF) components: $0.04 - 0.15\,\mathrm{Hz}$ and $0.15 - 0.4\,\mathrm{Hz}$, respectively (for more details, see Chapter 2). Pharmacological studies have found that stress typically causes an increase in SNS activity while reciprocally causing a withdrawal in PNS activity, a phenomenon known as the sympatho-vagal balance. However, in practice the response of the ANS to stress is diverse and depends on the nature of the stressor (physical, psychological) and in some cases the individual (Berntson & Cacioppo, 2004). For instance, a study of psychological stress found much greater changes in PNS activity for some individuals and SNS activity in others (Berntson, Cacioppo, & Quigley, 1991). Nonetheless it has been proposed that the LF/HF power ratio, a relative measure, can characterise the *balance* relationship between the SNS and PNS (Pagani et al., 1986) and has been widely used to study the effect of stress on performance.

Nakahara, Furuya, Obata, Masuko, and Kinoshita (2009) compared the LF/HF ratio elicited while musicians performed and listened to music, finding a higher ratio during performance. In their study, they asked thirteen elite pianists to undergo different performances, including the conditions of expressive piano playing, non-expressive piano playing, expressive listening and non-expressive listening. The results showed that the expressive condition not only triggered an increased LF/HF ratio, but also a significantly increase in the high-frequency activity. Furthermore, a greater modulation of both were observed during the expressive performance compared to the perception task alone. The findings suggest that the performance itself has a greater effect on the (emotion-related) modulation on the cardiac activity than the listening task, including a reciprocal change of sympathetic and parasympathetic nervous activity. Harmat et al. (2010) studied heart rate and heart rate variability in professional singers and flautists during low and high stress performances, and they found increased heart rate and suppressed heart rate variability in the high stress condition, but contrary to predictions from previous research (Berntson & Cacioppo, 2004), LF power was significantly lower in high stress. In another study, Harmat et al. (2010) examined heart rate and heart rate variability in expert pianists while playing a familiar piece and while sight-reading a technically demanding unfamiliar piece. They found significantly higher LF power in the latter condition, which corresponded to a more cognitively demanding and (by implication) more stressful task.

The ambiguities and inconsistencies encountered using the traditional LF/HF model might be explained by recent work (Billman, 2013; Schubert et al., 2009), which has argued that it over-simplifies the complex relationship between the SNS and PNS, and challenges its accuracy. Thus far, the assumption that the HF/HF reflects the sympatho-vagal balance has been expressed through the following hypotheses: Firstly, the the SNS activity is exclusively relevant for the activity in the LF power in the heart rate variability. Furthermore, the similar concept accounts for the PNS activity, which is allegedly predominately responsible for a peak in the HF power. Secondly, the consequences of physiological challenges through stress or any other physiological diseases trigger a reciprocal changes in the cardiac sympathetic and parasympathetic nerve activity, and are usually experienced by a diminish in the SNS and vice versa. Lastly, any changes in the SNS and PNS activity are based on a simple linear interaction and can be obtained through the extraction of the spectral density in the heart rate variability.

Recent studies, however have begun to challenge these assumptions and demonstrate the hypothesis aforementioned follow a too simplistic view on the humans' physiology to stress. Instead, Billman (2013) claims a more complex and non-linear interaction between both divisions of the autonomic nervous system, which has been predominantly shown in the ambivalent findings of the LF activity to stress. For instance, studies have found that beta-adrenoceptor blockade (a medication that inactivates the SNS) only leads to a reduction of LF power by up to 50%. Moreover, when both SNS and PNS activity were externally regulated, the LF/HF ratio showed an increase from the baseline of up to 80%, suggesting a false shift in the sympathetic dominance. To provide a similar example, other studies assessed the impact of interventions such as acute exercise on the cardiac sympathetic activity (Houle & Billman, 1999); although the results showed a large increase in heart rate, the LF/HF ratio remained unchanged, further strengthening the assumption that the relationship between the LF and HF is more complicated than previously postulated. This has motivated us to investigate more appropriate methods for modelling the variable interactions within R-R rhythms in conditions of stress.

Complexity science quantifies the ability of a living system to adapt to changes in the environment characterised by long term auto- and cross-correlations within its physiological responses (coupled dynamics) at different scales. Multiscale sample entropy (MSE) is one such method that evaluates signal regularity, determined by sample entropy, across multiple temporal scales and is particularly suited to revealing long-range correlations—a key property of complex systems (Costa et al., 2002; Costa, Goldberger, & Peng, 2005: for more details, see Chapter 2). In the context of heart rate variability, the MSE method has the advantage of being able to examine R-R fluctuations independent of their absolute magnitude (relative measure) with a high degree of accuracy (the algorithm is sensitive to nonlinear couplings) and without making rigid assumptions about the underlying generating mechanisms as is the case with the LF/HF ratio. Studies of stress level changes induced in heart rate variability by physical exertion (Turianikova, Javorka, Baumert, Calkovska, & Javorka, 2011) or meditation (Sarkar & Fletcher, 2014) suggest that complexity—determined by the MSE approach—is lowest during states of high stress, a result that is consistent with the complexity-loss theory. Despite the potential of the method in the study of stress the precise data conditioning and pre-processing steps undertaken prior to MSE analysis are often not reported, yet these have a major impact on the coherence and interpretation of the results.

Aims of the present study

Music is a natural domain for studying the response to high stress performance situations given that musical performance requires considerable motor precision integrated with sustained management of cognitive, perceptual and social processes (Williamon, 2004). While consistency in executing domain-specific skills over time is a characteristic of expertise in any domain (Ericsson, 2008), the degree of physical control exhibited by an expert classical musician in repeated performances (Hunsaker, 1994; Inesta, Terrados, Garcia, & Perez, 2008) offers a unique opportunity to study the degree of stress caused by public performance.

The heart rate variability of a concert pianist was assessed for performances of the same work in low stress and high stress conditions. We set out to dynamically examine stress signatures caused by (1) varying physical and cognitive demands within the musical piece (identical across performances) and (2) audience-induced anxiety (different across performances). For rigour, heart rate variability analysis was performed using standard and state-of-the-art techniques with identical pre-processing (considered frequency range, identical time windows) applied where relevant, in this way ensuring a fair comparison between the analysis methods.

3.1.1 Method

Participant

Melvyn Tan (born 1956) is an internationally renowned pianist and performs regularly in many of the world's leading concert halls.

Procedure

A preliminary health screening was first conducted. Electrocardiography (ECG) data were recorded for performances under a low stress condition, where only the performer and research team were present, and a high stress condition with an audience of 400 people at the 2012 Cheltenham Music Festival. The data were collected wirelessly at a sampling rate of 250 Hz using a Zephyr Bioharness (Johnstone et al., 2012a, 2012b). Analysis was focused on data obtained during the first piece in the recital programme, J.S. Bach's English Suite in A minor (BWV 807), where early stages of performance are particularly physically and psychologically stressful (Martens et al., 1990).

Data treatment

Each performance produced approximately 20 minutes of ECG data. The time difference between successive R peaks in ECG was estimated, which was converted into an R-R time series with samples at regular time intervals of 0.25 s using cubic spline interpolation. The R-R signal was bandpass filtered (0.04 −0.4 Hz) via a 4th order Butterworth filter before estimating the following features via overlapping windows of the same length:

- Standard deviation of the R-R signal about its mean
- Power in the low frequency (0.04 −0.15 Hz) and high frequency components (0.15 −0.4 Hz) of the R-R signal obtained using a 4th order Butterworth filter
- LF/HF ratio obtained from the estimated power in the LF and HF bands;
- Sample entropy (SE) estimated at different time scales for the complete frequency range (0.04 −0.4 Hz), the low frequency range (0.04 −0.15 Hz) and the high frequency range (0.15 −0.4 Hz). In all cases, each window segment was normalised (zero mean, unit variance) before estimating the SE with the embedding dimension and tolerance level at 2 and 0.15, respectively (see *Multiscale sample entropy* below).

Windows of 7 min length were selected as the longest period of the considered R-R component was 25 s (0.04 Hz) and incorporation of at least 10 times the lowest oscillation period are advised in heart rate variability analysis to sample short-term variations adequately (Berntson et al., 1997). It is worth noting that the LF/HF ratio and the MSE method, when estimated over normalised data segments, are relative measures, and do not depend on the absolute scaling of the R-R data.

Multiscale sample entropy (MSE)

MSE estimation is performed by two steps:

- The different temporal scales are estimated by coarse graining (moving average) the N-sample time series, xi, i=1,...N. For a scale factor, ε, the corresponding coarse-grained time series is given by: $y_j^{\varepsilon}=(1/\varepsilon)\ \Sigma_i\ x_i$ where i=(j-1)ε+1,..., jε and $j = 1, \ldots, N/\varepsilon$.

- The sample entropy (SE) is evaluated for each intrinsic scale $y_j\varepsilon$. Underpinning the method is the estimation of the conditional probability that two similar sequences will remain similar when the next data point is included. First, composite delay vectors of the scale are formed, with embedding dimension M, and the average number of neighbouring delay vectors for a given tolerance level, r, are estimated. This is known as the frequency-of-occurrence and reflects the level of self-similarity within the scale. This process is repeated for an embedding dimension of M+1, and the ratio of the two frequency-of-occurrence values gives the SE of the scale.

3.1.2 Results

Table 3.1 shows the completion time of each movement within the piece of music. The time difference between the two performances was 24 s, reflecting a high degree of consistency over a 20 minute task and enabling a fair comparison across performances. The performer reported an increase in perceived pressure during the performance in front of the audience. He furthermore reported that the Prelude and Courante (the first and third movements) were the most challenging in both scenarios.

Table 3.1: The times that the performer completed each of the movements for the low and high stress performances. *The performer reported that the Prelude and Courante were most challenging movements of the piece.

Movement	Low stress performance	High stress performance
Prelude*	255 s	259 s
Allemande	462 s	485 s
Courante*	563 s	578 s
Sarabande	802 s	814 s
Bourree I and II	1040 s	1048 s
Gigue	1236 s	1212 s

To provide insight into the level of resolution in time afforded by the standard deviation, LF/HF ratio and MSE methods, some of the movement ending times are shown in Figure

13.1 relative to the window length (7 min). Figure 3.2 show the results of the basic measures of heart rate variability. Figure 3.2*a* shows the R-R interval time series for the same performance under the low (grey line) and high stress (black line) performance conditions. The mean R-R interval for the high stress condition was significantly lower than that for the low stress condition (the Bhattacharyya coefficient, a measure of the amount of overlap between two distributions, was zero). Figure 3.2*b* shows the standard deviation of the R-R time series filtered within the frequency range $0.04 - 0.4$ Hz. The standard deviation was lower for the high stress performance (black line), conforming with some studies of the effects of stress on R-R standard deviation (Schubert et al., 2009). There was a high level of similarity between the relative changes in standard deviation for each of the two performances: the standard deviation decreased at around 600 s. This result may support the reported difficulty experienced during the Courante, which ended at 578 s (high stress performance), and indicates a reduction in stress possibly caused by the relief at having completed and passed through the most challenging parts of the piece, the reduced physical demands of the subsequent musical material, or both.

Figure 3.3*a* shows the total power in the LF bands (upper plot) and HF bands (lower plot). The high stress performance (black line) resulted in reduced HF activity but also in a decrease in the LF activity (grey line). Thus the LF/HF ratio, as shown in Figure 3.3*b*, was as expected for the initial stages of performance—it was highest for the high stress condition—but for performance times after approximately 600s the ratio of the low stress condition was highest. This runs counter to predictions of the physiological stress model based on an increase in the LF/HF ratio (Berntson & Cacioppo, 2004) and suggests that the ratio is inconsistent. Nonetheless, the relative decreases observed for the standard deviation features after approximately 600 s, potentially caused by the shift into less challenging movements of the piece, is also found in the LF/HF analysis.

Figures 3.3*c* and 3.3*d* show the results of the sample entropy (SE) analysis applied to the complete frequency range ($0.04 - 0.4$ Hz) for the first (no coarse graining) and second scale factors, respectively. The results indicate lower complexity, particularly at the second scale factor, for the high stress performance (black line), which is in agreement with previous

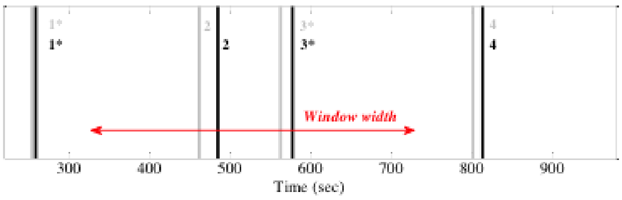


Figure 3.1: The vertical bars denote times that the performer completed the first four movements: (1) Prelude, (2) Allemande, (3) Courante and (4) Sarabande. Grey bars denote the end times for the low stress performance and black bars the end times for the high stress performance. The first and third movements, denoted by *, were reported as being the most challenging. The horizontal arrow represents the length of the window used in the standard deviation, LF/HF ratio and MSE analyses, providing some insight into the level of time resolution afforded by the methods.

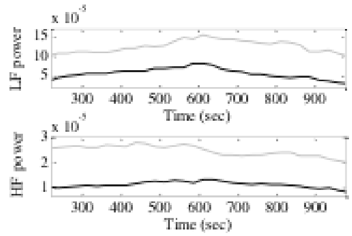
(a) The R-R interval time series. In all figures, grey lines denote the low stress performance, and black lines the high stress performance.

(b) The standard deviation of the R-R time series (bandpass filtered within the range 0.04 −0.4 Hz).

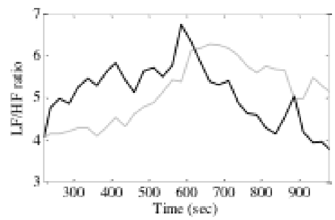
Figure 3.2: Results of the basic measures of heart rate variability.

results: high stress conditions yield lower complexity. In this way the results are similar to those for the LF/HF ratio (Figure 3.3*b*), and yet a greater separation between the two performances was facilitated by the MSE analysis (Figure 3.3*d*). Also, a relative increase in complexity was found in both the high and low stress performances at around 600 s, which is consistent with the standard deviation and LF/HF analyses.

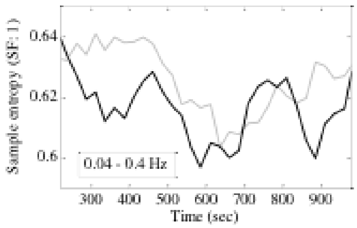
For the same scale factors, the SE of the LF band only is given in Figures 3.3*e* and 3.3*f*, and the SE for the HF band only is given in Figures 3.3*g* and 3.3*h*. The SE analysis for the HF band discriminates between the high stress (black line) and low stress (grey line) performances and is consistent with complexity loss theory, but there was no separation for the LF band. In both cases (Figures 3.3*e*-3.3*h*), however, a relative increase in complexity was not observed at around 600 s.



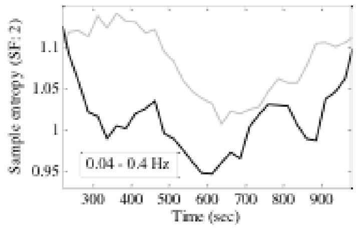
(a) The power in the low frequency band of the R-R time series (upper) and the high frequency band (lower).



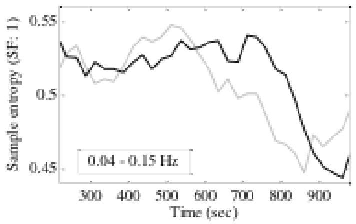
(b) The LF/HF ratio of the pre-processed (filtered, normalised) R-R time series.



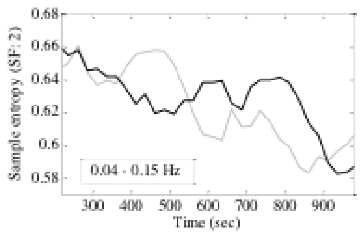
(c) The sample entropy (SE) for the first scale factor of the normalised time series, bandpass filtered within the range $0.04 - 0.4$ Hz.



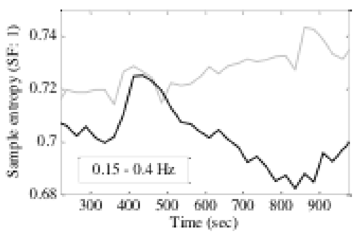
(d) The sample entropy (SE) for the second scale factor of the normalised time series, bandpass filtered within the range $0.04 - 0.4$ Hz.



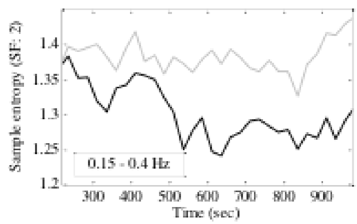
(e) The sample entropy (SE) for the first scale factor of the normalised time series, bandpass filtered within the range $0.04 - 0.15$ Hz.



(f) The sample entropy (SE) for the second scale factor of the normalised time series, bandpass filtered within the range $0.04 - 0.15$ Hz.



(g) The sample entropy (SE) for the first scale factor of the normalised time series, bandpass filtered within the range $0.15 - 0.4$ Hz.



(h) The sample entropy (SE) for the second scale factor of the normalised time series, bandpass filtered within the range $0.15 - 0.4$ Hz.

Figure 3.3: Results of the frequency and MSE measures of heart rate variability. In all figures, grey lines denote the low stress performance, and black lines the high stress performance.

3.2 Discussion

This study is the first rigorous examination of real-world autonomic response in the musical domain, demonstrating the degree of physiological change experienced by an expert musician when performing in public. Both standard and state-of-the-art tools were used to examine dynamically the components of heart rate governed by autonomic control, revealing signatures in heart rate variability that indicate higher stress levels caused by public performance and also technically challenging movements in the considered piece.

In this instance, basic measures (mean R-R, R-R standard deviation) were able to distinguish clearly between the states of low and high stress. The results of the standard deviation analysis also provide insight into the reported difficulties experienced by the performer during the first and third movements of the piece, as the relative values decreased once the third movement ended, suggesting a relative decrease in stress. It is well known, however, that such basic measures are not always reliable as disparate results have been reported in the literature (Billman, 2013). Another disadvantage is that these measures are based on the absolute magnitude of the R-R signal whereas, in general, relative measures of a process are understood to exhibit greater consistency.

The results of the two relative measures, the LF/HF ratio and the multiscale sample entropy (MSE) method, were similar when applied to the same R-R frequency components: both methods indicate a higher level of stress for the first part of the performance and both indicate a relative decrease in stress after the end of the third movement. However, the LF/HF ratio exhibits inconsistent results from 600 s suggesting the performance for the audience became less stressful than the performance without an audience, contradicting the reported experience of the musician. On the other hand, the MSE method clearly shows lower regularity across the intrinsic data scales for the state of high stress—indicating a lower complexity of the physiological state. The results are in agreement with the complexity-loss theory for living organisms under constraint: stress causes a reduction in complexity. In addition, it was found that the complexity of the HF band, typically associated with PNS activity, was reduced for the state of high stress. Little change in complexity was observed in the LF band.

At this point it is important to state that changes in the heart rate variability are not only caused by an *activation* of the SNS and the *calming* activity of the PNS. Although this metaphor has more relevance when it comes to alteration in the cardiovascular responses, in other parts of the ANS it may be the PNS that functions as the main drive to increase the body functioning (Levenson, 2014). For instance, the PNS is responsible for an increase in the activation of the salivary glands, the production or tears and the activity of the stomach and the intestine.

The second and third misconception that needs to be considered is that (1) the heart rate variability and the respiratory sinus arrhythmia are indexes of the entire vagus nerve or, an even more detrimental assumption, the entire PNS, and that (2) the ANS is primarily responsible to cause an increase or a decrease in activity of the targeted organ. In reality, the main bulk of the neural traffic in the vagus nerve is not efferent rather than afferent in nature, with vagal fibres that collect information of the body state and transmit the information back to the brain (for more details, see Chapter 1). Such afferent function is crucial when considering and theorising about the role of the ANS and the stress of performing from a *bottom-up* process (e.g., the emotion experienced and the cognition during performing affects the activity of the ANS: Levenson, 2014).

As such, while this case study offers valuable insight into how MSE analysis can be applied to data collected in real-world contexts, subsequent investigations are needed to establish the extent in which the results generalise to larger samples of expert performers and to those at lower levels of skill. Also, the MSE method should be extended to investigate jointly the dynamics of other physiological parameters (e.g., respiration rate) under stressful conditions. Finally, the utility of physiological complexity as a measure in stress-reduction interventions needs to be investigated, such as in cognitive-behavioural training or biofeedback. The findings reported here also offer promising new avenues for identifying stress responses in a wide range of performance situations, both in music and in other performance domains.

4 | Changes in heart rate variability before and during musical performance

4.1 Introduction

The reactivity of heart rate variability has been examined under a variety of performance conditions, such as public speaking (Pull, 2012) and sports competitions, including BMX races (Mateo, Blasco-Lafarga, Martinez-Navarro, Guzman, & Zabala, 2012), judo (Morales et al., 2013) and volleyball (D'Ascenzi et al., 2014). Blasquez, Font, and Ortis (2009), for instance, compared state anxiety and heart rate variability during a baseline measure to a competition in swimmers, detecting a significant elevation in state anxiety, LF power and the LF/HF ratio, while a significant parasympathetic withdrawal was observed by a diminished HF power. Similar outcomes were provided by Mateo et al. (2012), examining eleven BMX drivers in a two-day competition in contrast to a two-day baseline (training) measure. Monitored was competitive state anxiety and heart rate variability during a 20-minute pre-performance period and the actual performance. The heart rate variability was analyzed in terms of its frequency distributions and the degree of beat-to-beat self-similarities. The index of self-similarity is extracted by the application of sample entropy. The results showed significant elevated competitive state anxiety, as well as a significant effect of all six conditions, indicating a slow down in the vagal tone expressed by a decreased HF power and sample entropy during the pre-performance period in both days of the competitions and compared to the baseline measure. Morales et al. (2013) examined the changes in heart rate variability before judo competitions in 24 athletes of different level of national and international performance experience. Each participant rated their level of competitive anxiety using the the Revised Competitive State Anxiety Inventory (CSAI-2R) and their heart rate variability was recorded during both an official and unofficial competition. The heart rate variability was analysed using frequency domain analysis. The results showed that international-standard athletes have a higher confidence, mean R-R interval, standard deviation of R-R, square root of the mean squared difference of successive R-R intervals, short-term variability, long-term variability compared to national-standard judo athletes. The hypothesis that judo athletes with international-standard experience lower anxiety than their less-experienced counterparts was verified. In addition, the national-standard judo athletes showed a higher pre-competitive anxiety which was associated with a an increase in sympathetic and a decrease in parasympathetic activity. In particular, the HF power was significantly higher in international-standard athletes than in national- standard athletes. In contrast, the LF/HF ratio was higher in less experienced athletes, and greater in official competitions than in unofficial competitions, while the LF activity showed neither a significant effect of the type of competition nor an interaction between level of experience and type of competition.

These studies have provided evidence that heart rate variability reflects changes in stress levels in the pre-performance period—the time before a performance is due to commence—characterized by a decreased physical and cognitive adaptability during pre-task appraisal; this in turn shapes physiological stress responses and quality of performance (Hanin & Hanina, 2009). Yet, to date there are no systematic studies of comparative stress responses in the pre-performance vs. performance period, not a consensus on the duration of those periods—open literature reports the examined periods ranging from several minutes up to a day. Musical performance is a particularly fruitful domain for studying and understanding reactivity to psychosocial stress (Williamon, 2004). Professional musicians must deliver consistently high quality performances for knowledgeable and demanding. The physical, environmental, and cognitive demands of musical performance often lead to increased levels of anxiety and self-efficacy, which may have detrimental effects on the performance quality. The outcomes of a single performance may determine—or at least believed by the musicians to be determining—the course of their careers (Brodsky, 1996). While the psychology of music performance has been studied for several decades, corresponding investigations of cardiovascular reactivity to performance stress, and in particular to the critical timing of that reactivity, have been limited.

Craske and Craig (1984) examined physiological stress reactivity of 40 musicians over the 3-5 minute periods both in private in public. Heart rate was extracted at 100, 40, and 10 s prior to and 120, 140, 260 and 400 s after the first note played, and the musicians' state anxiety (Spielberger et al., 1983) was measured before each performance. The results indicate that the heart rate, when collapsed (averaged) together at times prior to and during playing, significantly differed between the two conditions, with the performance in public triggering both the highest physical arousal (objective measure of autonomous body response) and reported state anxiety (subjective measure). Abel and Larkin (1990) recruited 22 musicians to perform in front of a panel of judges. The pre-performance time was divided into two anticipatory periods: a warm-up period (5 min before) and the time between the final stage call and the performance (2 min before). The heart rate was extracted 12 times per min at baseline for 6 min, as well as for the 5-minute warm-up period and the 2-minute final call. State anxiety (Spielberger et al., 1983) was also measured at baseline and in each anticipatory period. They reported elevated levels of the heart rate and state anxiety during the two anticipatory periods compared with baseline measurements, with the highest physiological reactivity and state anxiety in the period immediately prior to entering the stage. However, the validity of this study was compromised by the fact that heart rate was not collected during the performance itself, which prohibits direct comparison with the pre-performance periods.

The above studies indicate that there are at least two reasons for a void in the current literature when it comes to the conclusive evidence of timing and degree of musicians' cardiovascular reactivity to acute psychosocial stress. Firstly, the existing studies were based on heart rate rather than heart rate variability (Abel & Larkin, 1990; Brotons, 1994; Craske & Craig, 1984; Yoshie, Shigemasu, et al., 2009), yet it is the frequency domain analysis of heart rate variability that yields clinically relevant frequency components (Milicevic, 2005) in ECG (for more details, see Chapter 2). Secondly, current studies offer no hard-and-fast rule on the duration of pre-performance periods, ranging anywhere from 100 s to 5 min, nor a consensus on interval lengths for the monitoring of heart rate variability, which leaves open the key issue of the selection of parameters for the detection of subtle changes in physical body response (for more details, see Chapter 2).

To this end, the structural complexity of heart rate variability has recently attracted significant attention in the investigation of cardiovascular response to psychosocial stress (Peng, Havlin, Stanley, & Goldberger, 1995). The use of MSE in analysing the performance-related stress is quite intuitive: (1) an unconstrained human system adapts freely to a constantly changing environment and therefore exhibits high MSE at larger scales (high complexity); (2) stress is an inhibition restricts the freedom in non-linear dynamics of heart rate variability and other stress biomarkers thus resulting in lower sample entropy values at higher scales (i.e., low complexity: Gao et al., 2013). It is therefore both convenient and physically meaningful to examine the stress signatures in musicians within the so-called *complexity loss theory* which states than an organism under constraints (illness, ageing, any other inhibition) exhibit lower complexity (MSE level are higher scales) of its physiological responses compared to a healthy, unconstrained, organism. Existing studies analysed heart rate variability in the context of mental stress (Visnovcova et al., 2014), cardiovascular disease (Tuzcu et al., 2006) and public performance (Williamon et al., 2013), and have provided conclusive evidence of lower complexity in heart rate variability with increased stress (Costa et al., 2002; Costa, Goldberger, & Peng, 2005). To put this into context, Visnovcova et al. (2014) for instance, studied the complexity and time asymmetry of short-term heart rate variability by evaluating participants' ECG at rest and during and after two stressors, including the commonly known and widely established Stroop test and an arithmetic test in 70 healthy participants. Heart rate variability was analysed using the spectral powers in low and high frequency bands. The results revealed a withdrawal in vagal activity by mean of a loss in the HF power in both stressors, and a significant increase in LF power during the Stroop task.

In contrast, the arithmetic task caused a reverse effect, a significant decrease in LF power, which the authors assume is a result of the different intensity in stress between the two tasks. Similarly, Tuzcu et al. (2006) assessed changes in heart rate complexity prior to the onset of atrial fibrillation (i.e., condition that leads an irregular and often abnormal increase in heart rate). 25 patients's ECG was monitored during two 30 min time intervals and the recording was divided into three 10 min segments. The data was evaluated using sample entropy used in complexity science. The results showed that the sample entropy for the R-R fluctuations were significantly reduced before the period of the atrial fibrillation (lowest sample entropy was observed during the last 10 min prior the onset) compared to the time after the atrial fibrillation.

As shown in Chapter 3, where I examined complexity of heart rate variability of an expert pianist for the first 20 minutes of a low- and high-stress performance, results show that: (1) complexity of heart rate variability significantly decreased during the high-stress performance, and (2) the MSE analysis exhibits much higher discrimination in distinguishing between the stress conditions. While this pilot study was the first finding of its kind in real-world (non-laboratory) performance conditions, further investigations over larger number of musicians, across a variety performance contexts, and benchmarking against the anxiety self-tests are required for a conclusive proof-of-concept, a subject of this chapter.

4.1.1 Method

Participants

Eleven violinists from the Royal College of Music, London, and six flautists from the Conservatory of Southern Switzerland, Lugano, participated in the study (9 men, 8 women; the mean age and standard deviation (*SD*) were: 23.23 years, *SD*= 2.84). Participants were required to give multiple, polished performances, of the *Allemande* from J. S. Bach's Partita No. 2 in D minor for solo violin (BWV 1004) or the *Allemande* from J. S. Bach's Partita in A minor for solo flute (BWV 1013). The research was granted ethical approval by the Conservatoires

UK Research Ethics Committee and was conducted according to ethical guidelines of the British Psychological Society. Informed consent was obtained from all participants, and no payment was given in exchange for participation.

ECG

For the violinists, ECG was recorded using a wireless commercial device 80x40x15mm, weight 35g), the Zephyr Bioharness, which snaps onto an elasticated chest belt (width 50mm, weight 50g) and operates at a sampling rate of 250 Hz (for more details, see Chapter 2).

For the flautists, data were collected using a well-established PowerLab (Radespiel-Troeger, Rauh, Mahlke, Gottschalk, & Muck-Weymann, 2003) recording device (model 26T), with electrodes attached to the chest and in intercostal spaces (wherever possible between ribs VI and VII). A further electrode was positioned between ribs VI and VII; the raw signal was acquired at a sampling frequency of 1000 Hz.

State anxiety

Prior to each performance, participants completed Form Y1 (state anxiety) of the State-Trait Anxiety Inventory (STAI: Spielberger et al., 1983), a 20-item questionnaire measuring the emotional state a person is experiencing based on subjective feelings of nervousness and perceived activation and arousal (for more details, see Chapter 2). To put our results into context, moderate levels of anxiety in young men give the score of 36.47 (SD = 10.02) as compared to 38.76 (SD = 11.95) for young women.

Procedure

Induction session At the start of the study, each of the 17 participants attended a 20-minute induction session, at which point they confirmed that they would be able to deliver multiple, polished performances (with written repeats) of either the *Allemande* from J. S. Bach's Partita No. 2 in D minor for solo violin (BWV 1004) or the *Allemande* from J. S. Bach's Partita in A minor for solo flute (BWV 1013). They also provided background information on their musical experience, and a preliminary health screening was conducted. On explicit questioning, all participants confirmed that they were not currently taking anxiolytic medication or other substances that may affect their perceptions of or alter any physiological responses to performing.

Low- and high-stress performance conditions The musicians were asked to arrive 30 minutes before each of two scheduled performances to be fitted with the Bioharness (violinists) or electrodes (flautists) and to prepare for their performance as they would normally (e.g., warming-up, tuning, rehearsing, etc.). Stage calls were given by a member of the research team—acting as the backstage manager—at 15 min and 5 min before. At 0 min, participants were escorted to a backstage area, asked to complete Form Y1 of the STAI, and required to wait a further 5 min while the backstage manager confirmed that the performance space was adequately prepared. ECG recordings made during this time are referred to below as the *pre-performance* data. They then entered either an empty room (low stress) or a room with an audition panel with three adjudicators (high stress), where they were asked to perform the designated piece lasting 5.06 min (*SD*=0.22) for the violinists and 5.19 min (*SD*=0.10) for the flautists, referred to below as the *performance* data. The order of conditions was counterbalanced, and participants were informed in advance of whether they were to perform in the empty room or for the audition panel. ECG data were recorded throughout each session, and all performances were video recorded. The performance protocol is summarised in Figure 4.1.

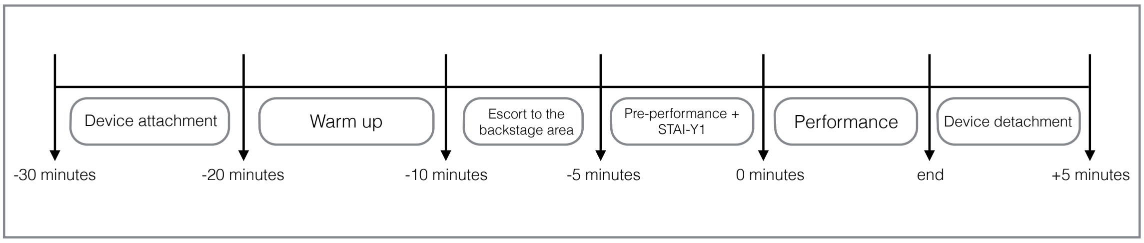


Figure 4.1: Performance protocol.

Data treatment and analyses

The ECG data were prepared using MATLAB (R2013a) and analysed in SPSS (version 22).[1] R-R intervals were detected using cubic spline interpolation and median filter with samples at regular time intervals of 0.25 s. After applying the fourth-order Butterworth filter, the mean and standard deviation of the R-R, LF and HF components, the LF/HF ratio and the SE features were calculated for both the pre-performance and performance data (for more details, see Chapter 4).

Preliminary comparisons of ECG measures between the violinists and the flautists, as well as the impact of breathing on heart rate variability, revealed no significant differences or interactions; therefore, data from the two samples have been combined and presented as one dataset. Subsequently, for all extracted features, a repeated measures analysis of variance (ANOVA) with Greenhouse-Geisser correction was calculated, examining the effect of time (pre-performance versus performance), condition (low-stress versus high-stress performance), and their interaction.[2] The state anxiety inventory (STAI-Y1) administered before the low- and high-stress performances was analysed using a paired-samples t-test.

[1]MATLAB is a research tool that enables psychologists to develop and design very every step of our research. It allows for the use of various stimuli such as pictures and sounds and enabled to operate statistical tests, to run simulations and to execute any kind of signal processing (e.g., bio-signal analysis or image resolution improvement: Borgo, Sornazo, & Grassi, 2012). For anyone who is interested in using the MATLAB codes developed and used in this thesis, please email: lisa.aufegger@rcm.ac.uk.

[2]The repeated measures ANOVA, or also called one-way ANOVA is applied for dependent groups who undergo an assessment at different time points. It is an extension of the t-test and looks at (significant) differences between means. The ANOVA requires and independent and and dependent variable which needs to be interval (or ratio) and ordinal, respectively.

4.1.2 Results

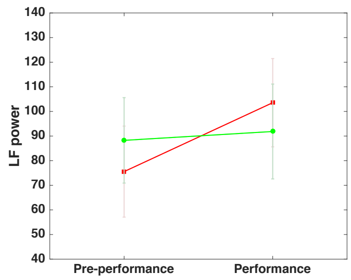
LF power, which is generally associated with SNS activity and the baroreceptor reflex, showed a significant effect of time ($F_{1,16}$=10.139; p<0.01; ηp^2=.38), no significant effect of condition ($F_{1,16}$=0.24; p=0.88; ηp^2=.01), and a significant interaction between time and condition ($F_{1,16}$=11.725; p<0.01; ηp^2=.42). Figure 4.2a shows LF before and during the low-stress and the high-stress performances. LF increased from pre-performance to the performance period in the low-stress condition, reflecting an increase in reactivity over time, while remaining stable throughout the high-stress condition.

HF power, generally associated with PNS activity and the respiratory sinus arrhythmia, showed a significant effect for both time ($F_{1,16}$=15.280; p<0.01; ηp^2=.48) and condition ($F_{1,16}$=8.911; p<0.01; ηp^2=.35), with no significant interaction between time and condition ($F_{1,16}$=0.003; p=.95; ηp^2=.00). As shown in Figure 4.2b, HF power was generally more elevated in the low-stress performance, and for both conditions, it increased from pre-performance to performance.

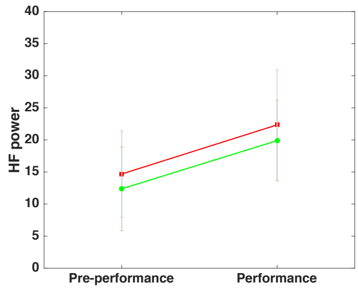
The LF/HF ratio, which is an indication of the sympatho-vagal balance with higher ratios suggesting higher overall stress levels, showed a significant effect of time ($F_{1,16}$=6.848; p<0.05; ηp^2=.30) and condition ($F_{1,16}$=9.763; p<0.01; ηp^2=.37) and a significant interaction between time and condition ($F_{1,16}$=10.914; p<0.01; ηp^2=.40). Figure 4.2c shows that there was an elevated LF/HF ratio in the pre-performance period for the high-stress condition, indicating that physiological response to high stress peaked during the anticipatory period in line with previous research (Craske & Craig, 1984; Williamon, Aufegger, & Eiholzer, 2014). However, the results indicate that physiological response during the high-stress condition then reduced to levels comparable with those of the low-stress condition. This latter, somewhat perplexing finding concurs with the results of Chapter 1, in which standard heart rate variability frequency domain analysis was shown to be less accurate at assessing average stress response than the new MSE method.

The sample entropy scale factor 2 for the full frequency spectrum ($0.04 - 0.4\,\text{Hz}$)

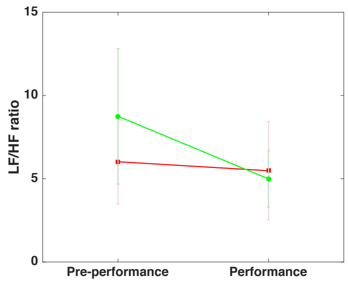
demonstrated a significant effect of time ($F_{1,16}$=25.127; p<0.001; ηp^2=.49) and condition ($F_{1,16}$=15.940; p<0.01; ηp^2=.61), and no significant interaction between time and condition ($F_{1,16}$=.214; p=.65; ηp^2=.01). In both the low- and high-stress performances complexity for the full frequency spectrum was lowest during the pre-performance period, reflecting greater reactivity, and increased in the performance period, reflecting a reduction in reactivity (Figure 4.2d). As predicted from the results of Williamon et al. (2013), the lowest complexity, indicating the greatest stress reactivity, was found in the high-stress performance.



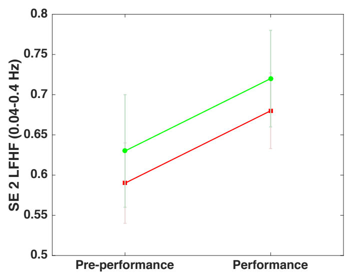
(a) The power in the low frequency band of the R-R time series.



(b) The power in the high frequency band of the R-R time series.



(c) The LF/HF ratio of the pre-processed (filtered, normalised) R-R time series.



(d) The sample entropy (SE) for the second scale factor of the normalised time series, bandpass filtered within the range $0.04 - 0.4$ Hz.

Figure 4.2: Results of the frequency and MSE measures of heart rate variability. In all figures, green lines denote the low stress performance, and red lines the high stress performance.

Table 4.1: Descriptive statistics for the extracted heart rate variability features of pre-performance versus performance period in the low- and high-stress condition.

Feature	*Low-stress performance* Before	*Low-stress performance* During	*High-stress performance* Before	*High-stress performance* During
LF power	75.56 (18.49)	103.55 (17.93)	88.25 (17.35)	91.85 (19.26)
HF power	14.69 (6.77)	22.34 (8.59)	12.38 (6.52)	19.89 (6.29)
LF/HF ratio	6.02 (2.54)	5.48 (2.95)	8.75 (4.07)	4.99 (1.70)
SE LF+HF	0.59 (0.05)	0.68 (0.04)	0.63 (0.07)	0.72 (0.06)

State Anxiety

The musicians' state anxiety significantly increased from the low- (mean=34.00, *SD*=7.78) to the high-stress condition (mean=38.71, *SD*=7.03; $t_{(16)}$= -2.735; p<.05).

4.2 Discussion

This study examined the degree of cardiovascular reactivity experienced by musicians before and during performances in low- and high-stress conditions. This was achieved by analysing power spectral density of heart rate variability and by using the state-of-the-art sample entropy analysis of heart rate variability. The sample entropy approach made it possible to achieve robust discrimination of the underlying features related to the dynamics of the heart regulated by the autonomic nervous system. The analysis indicated that highest stress reactivity levels are elicited in the pre-performance period, compared with that during performance, particularly so in the high-stress condition. For rigour, these objective stress metrics were benchmarked against the subjective self-reported state anxiety scores by the musicians.

The standard heart rate variability frequency analysis showed a statistically significant increase in the LF but not the HF spectral power in heart rate variability from the pre-performance to the performance period, suggesting a modulation of both the sympathetic and parasympathetic nervous systems during the physiological act of performing music. Between performance conditions the HF power was as expected higher for the low-stress condition, suggesting an increased PNS activity and more relaxed physical state. Conversely, the LF power, which is believed to reflect the SNS activity and to be increased during stress, was more elevated in the high-stress condition. While this result does not confirm the commonly believed relationship between the LF power and the SNS in response to stress, is in agreement with more recent studies that postulate that the LF power does not accurately reflect the SNS activity. When analysing both the LF power and HF power together via the LF/HF ratio, we observed the highest level of physiological stress reactivity in the pre-performance period, when musicians were simply waiting to perform. In contrast, the LF/HF ratio then decreased to levels comparable with the low-stress condition during the actual performance—a counterintuitive result that requires further investigations.

The sample entropy analysis confirmed this greater stress response (lower complexity) in the pre-performance period, but unlike the standard heart rate variability frequency domain analysis, the more powerful sample entropy has been able to identify a higher state of stress during the high-stress performance.

This study is not without limitations. The results of this study are somewhat limited by the rather modest sample size and focus on heart rate variability only. Future studies may, therefore, consider a larger sample alongside additional physiological and psychological measures such as electroencephalographic data, breathing or musicians' flexibility to adapt emotionally, cognitively or behaviourally to psychosocial stress. This may, for instance, be done by comparing musicians' heart rate variability and breathing alongside coping strategies, self-efficacy or overall performance quality during different performance events and in different performance contexts (Elliot, Payen, Brisswalter, Cury, & Thayer, 2011). Secondly, while this study provides an in-depth understanding of peak stress responses, subsequent studies should investigate how the MSE method may be used to interpret physiological control (Tan, 2013; Tan et al., 2009). This may enable future research to build upon pre-performance stress reduction tools as an attempt to seek control over highly stressful situations.

In summary, the results shown an increase in LF and HF power from the pre-performance to the performance period, suggesting a dominant modulation of both the sympathetic and parasympathetic nervous systems during the physical act of making music (Berntson & Cacioppo, 2004; Inesta et al., 2008); however, taking both the LF and HF together via the LF/HF ratio, the results show that the highest level of physiological stress reactivity occurs in the pre-performance period, while musicians are simply waiting to perform. The results of the MSE analysis overall confirmed a greater stress response (lower complexity) in the pre-performance period, but unlike the standard heart rate variability frequency domain analysis, the MSE, in particular for the full frequency spectrum, was able to show greater separation of physiological stress responses within and between each performance condition.

5 Introducing simulation training

5.1 Introduction

Exceptional musical performances require an ability to execute complex physical and mental skills on stage under intense pressure and public scrutiny. While many of these skills can be honed through deliberate practice (Ericsson, Krampe, & Tesch-Roemer, 1993), opportunities to gather experience on stage, which is simultaneously rich in contextual complexity and yet safe to allow musicians to experiment and develop artistically, are rare. Here, we report a new educational and training initiative aimed at creating realistic, interactive performance scenarios using simulation.

A high quality virtual environment should offer a three dimensional visual experience of weight, height, and depth and provide '. . . an interactive experience visually in full real-time motion with sounds and possibly with tactile and other forms of feedback' (Roy, 2003, p. 177). The more elaborate the quality of the simulation, the more the feeling of immersion and perception of *reality* that is experienced by users. This also depends on the level of interactivity, dimensionality, accuracy, fidelity, and sensory input and output (Satava, 1993). When these features are addressed, simulation can be used as a performance tool to explore and study specific behaviours and as an educational tool to acquire and practice skills (Axelrod, 1997; Gallagher et al., 2005).

Thus far, successful application of virtual training environments has been shown in studies addressing fears of heights, flying, spiders, and public speaking. Pertaub, Slater, and Barker

(2002), for instance, showed significant increased signs of anxiety in people with phobias when speaking in front of a neutrally behaving virtual audience. By comparing somatic and cognitive features, including the Personal Report of Confidence as a Public Speaker (PRCS) as well as heart rate measurements before, during and after the performance, results suggest that such exposure could be an effective tool for treatment. A follow-up study by Slater, Pertaub, Barker, and Clark (2006) employed virtual audiences who could respond neutrally, positively, and negatively. Their verbal responses included expressions such as 'I see' or 'That's interesting,' moving to more evaluative statements like 'That's absolute nonsense.' The audience was also able to provide non-verbal cues such as shifts in facial expression, changes in posture, and short animations including yawning, turning their heads, or walking out of the room. The results of comparing subjective measurements (e.g., PRCS) before and after virtual exposure showed that the way the audience responded directly affected participants' confidence as public speakers, in that positive audience reactions elicited higher confidence levels while the negative response caused a significant reverse effect.

Virtual environments have also been shown to be an effective tool for training elite performers, such as pilots, athletes, and surgeons, especially when they have relatively little exposure to real-world performance contexts or when failure carries career- and/or life-threatening risks. In surgery, for example, such training, compared with more traditional methods, has been shown to reduce the number of errors in surgical procedures, enhance the rate and extent of skill acquisition, and improve planning strategies (Grantcharov et al., 2004). It not only helps trainees who lack experience in real-world surgical contexts but also advanced surgeons who require exposure to new procedures and technologies (Sutherland et al., 2006).

Seymour et al. (2002), for example, demonstrated a significant improvement in postgraduate residents' psychomotor skills in conducting laparoscopy compared to a control group. The virtual reality was generated by means of a PC, a video, as well as two laparoscopic interface input devices. After 10 one-hour training sessions, all participants performed a laparoscopic cholecystectomy with one of the surgeon-investigators that was blind to the assignment. The results showed that training in the VR produced fewer errors and a more steady progress than in the control group. Lendvay et al. (2013) compared the impact of a 3- to 5-minute warm up using a virtual reality display on the quality of a conventional laparoscopy to a control group. Evaluated were the task time, the tool path length, the economy of motion, and the technical and the cognitive errors. In total, four training sessions were carried out, each 24 hours apart. Advantages of the virtual reality training were found in the path length, the task time, and the cognitive error (e.g., out of order) after the first three sessions.

To a limited extent, virtual environments have been employed in music, where studies have tested their use in managing music performance anxiety. To date, the effects of exposure in these settings on psychological and physiological responses to performance stress are mixed. On the one hand, exposure to performing conditions using simulation has been shown to decrease state anxiety significantly compared with a control group, particularly for those musicians who score higher on trait anxiety measures (Bissonnette, Dube, Provencher, & Moreno Sala, 2015). On the other, Orman (2003) and Orman (2004) found no discernible, consistent patterns of change in either self-reported anxiety levels or heart rate for musicians taking part in an intervention offering graded exposure to stressful performance situations. Such inconsistent results can also be found in other domains, for instance in studies examining surgical performance by Moktar et al. (2016) and Torkington, Smith, Rees, and Darzi (2001), who compared simulated training against more conventional training and no training at all. This emphasises the importance of the backgrounds of individual participants, their levels of immersion (i.e., how realistically they experience the environment), and the quality of the interface on the overall effectiveness and range of uses of a virtual environment.

In terms of the studies conducted in music, it is possible that the inconsistent findings are due to differences in the fidelity and interactivity of the simulations used, but in addition, several methodological limitations should be highlighted in the extant research. Firstly, participants' use of anxiolytic medication and other substances that may have affected their perceptions of or physiological response to stress was not controlled. Secondly, while heart rate was measured in all studies, there were limitations with how the data were reported (Orman, 2003, 2004), or the results were not reported at all (Bissonnette et al., 2015). Concerning the former, stressful events have been shown to influence temporal fluctuations of the peak-to-peak times in the electrocardiogram (ECG), the R-to-R (R-R) interval, known as heart rate variability (Berntson & Cacioppo, 2004). While the simplest measures of heart rate variability are the mean of the R-R time series and the standard deviation about its mean, both of these statistics are based on the absolute magnitude of the R-R interval. However, in many applications, relative measures such as the power ratio of the low- and high-frequency components of heart rate variability allow for more reliable comparisons between participants (Pagani et al., 1986) (for further information, see 'Data treatment and analysis' and Williamon et al. [2013]). Finally, the existing studies test the hypothesis that performance exposure using virtual environments can ameliorate psychological and physiological symptoms of performance anxiety; while this seems plausible on the surface, the inter- and intra-individual variability in how people experience and interpret such symptoms can be extremely large (Williamon, 2004). Given the multifaceted nature and impact of performance anxiety on musicians and the personal significance it holds even for highly experienced performers (Kenny, 2011), mere exposure to performance situations can be seen as the first of many steps in identifying and managing pernicious anxiety-related problems. Rather, it is possible that anxiety management will be only one of many possible uses of simulation training for enhancing musicians' learning and performance.

The aim of our research was to design, test, and explore possible uses of new interactive, simulated environments that provide salient cues from real-life performance situations—in this case, a recital and an audition. The environments were designed on the principles of *distributed simulation*, in which only a selective abstraction of environmental features are provided. Distributed simulation has been tested and applied widely in the field of surgical education, where fully-immersive virtual operating theatres are expensive to build, maintain, and run. The findings suggest that, indeed, a simulated environment only requires few environmental cues above and beyond the interactive simulation of an injury, wound, etc. in order to produce significant advancements in learning surgical techniques compared with more common training methods (Kassab et al., 2011). For instance, these may include a scaled-down operating lamp, background sounds played through loud speakers, and even life-sized pictures of machines commonly found in operating theatres; as the surgeons themselves do not operate such equipment and must focus on performing the procedure at hand, the imitated (yet plausible) environmental features often go unnoticed while adding significantly to the level of immersion experienced by participants. This approach has resulted in low-cost, convincing simulations that are portable, widely accessible, and can be used in almost any available space. In our study, advanced violin students performed the same piece in performance settings that employed a selective abstraction of recital and audition environments. The musicians' perceptions and experience of performing in the environments were obtained through questionnaires, and for a subset of participants, ECG data were recorded during their performances.

5.1.1 Method

Participants

Eleven violinists (6 men, 5 women; mean age=22.45 years, *SD*=2.25) were recruited for the study through the Royal College of Music's (RCM) student email list. They had been playing the violin for 16.18 years (*SD*=2.75), including their first performance at age 6.50 (*SD*=2.20). All students performed regularly (mean=2.32 times per month, *SD*=1.30) and practiced on average for 3.93 hours per day (*SD*=0.85).

A subset of 7 participants from the larger sample (4 men, 3 women; mean age=22.57 years, *SD*=2.50) were selected based on their availability to take part in an additional performance for a real audition panel. These musicians had been playing for 16.00 years (*SD*=3.21), with their first performance at age 7.57 (*SD*=2.14). They performed for audiences on average 2.00 times per month (*SD*=1.15) and practiced for 3.89 hours per day (*SD*=0.93).

This study was granted ethical approval by the Conservatoires UK Research Ethics Committee and was conducted according to ethical guidelines of the British Psychological Society. Informed consent was obtained from all participants, and no payment was given in exchange for participation.

The performance simulator

The performance simulator was developed by the RCM and the Conservatorio della Svizzera Italiana.[1] The aim was to generate back-stage and on-stage environments using a selective abstraction of key features consistent across a wide range of Western classical performance venues. The selection of these features was informed by interviews with advanced musicians on their experiences and perceptions of performing and on further pilot interviewing focused on performance environments. By undertaking user research, interviewing staff and students from the RCM and watching performances from backstage, common features could be identified and then recreated, including interaction with a backstage manager, the ritual of walking on stage, using appropriate lighting and sound cues (see Figure 5.1), and providing realistic, interactive virtual audiences of different types and sizes.

With these features in mind, the simulator was designed along the principles of distributed simulation (i.e., low-cost and portable, with high fidelity) to operate in two modes:

- a recital with 24 virtual audience members
- an audition situation with three 'expert' virtual judges

In both simulations, pre- and post-performance protocols were employed that matched those found at leading international performance venues—for instance, entrance to a 'green room' for warm-up, stage calls at regular intervals, and scripted procedures for entering, bowing, and exiting the stage (see 'Procedure').

Recital simulation To create an interactive audience and capture plausible audience behaviours, 11 concert-goers were filmed individually using green-screen technology sitting still while listening to a Western classical performance (with naturalistic body swaying, fidgeting movements, and coughing) and responding to a successful or unsuccessful performance with a standing ovation, enthusiastic applause, polite applause, or aggressive booing

[1] In particular, I contributed to development of the 'audition panel' in the simulator.

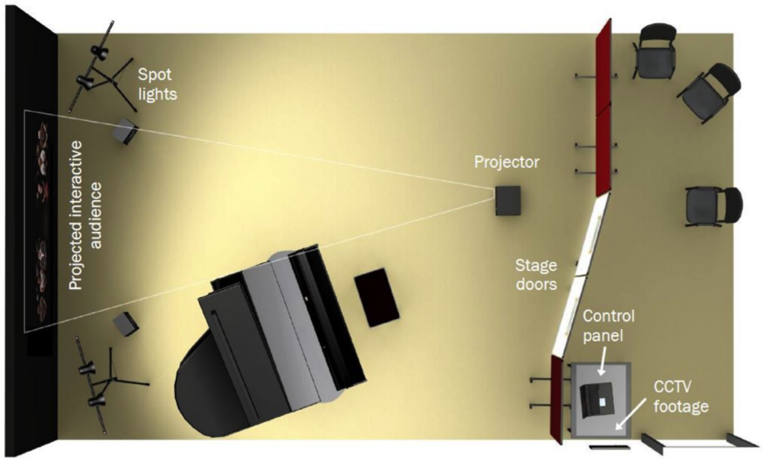


Figure 5.1: Set up of the simulation

and displays of displeasure. They performed these tasks on the same approximate timeline, achieved by having them watch a video of an actor mounted next to the video camera and asking them to synchronise their behaviours with those of the actor. They were filmed individually so that audiences of different sizes could be compiled. For the purposes of this study, the audience consisted of 24 people seated in two blocks of chairs situated in a small auditorium designed using Adobe Illustrator (CS 5) and Photoshop (Figure 5.2). A Flash interface was created to enable the audience to be manipulated using pre-set control commands from a computer console located in the backstage area.

In terms of environmental cues, the backstage area was equipped with CCTV footage of audience members taking their seats in an auditorium (Figure 5.2). On stage, there were spot-lights and curtains on both sides of the projected audience. Noise distractions such as coughing, sneezing, and phone ringing were included in the stage area played through loudspeakers. Recordings of these as well as all applause and booing were made separately by another group of 16 volunteers in an anechoic chamber. Small recital hall reverberation was added to these recordings and then synchronised and layered on top of the video footage.

Figure 5.2: The CCTV footage and the virtual audience

Audition simulation The members of the simulated audition panel were three professional actors who were filmed together sitting behind a table. Starting each audition with a neutral ‘Hello, please start whenever you are ready,’ the panel showed typical evaluative behaviours such as making notes, looking pensively, and leaning back while simultaneously portraying positive, neutral, or negative facial expressions and behavioural feedback during the performance (e.g., smiling or frowning; leaning in toward the performer, or folding arms and leaning back). Each mode of listening was presented in loops of 5 minutes; the research team could change the mode of response after the loop or immediately. At the end of the performance, the audition panel could respond to the performance in a positive, neutral, or negative fashion—for instance, an enthusiastic ‘Thank you, that was excellent’, a polite but non-committal ‘Thank you very much’, a disappointed sigh followed by ‘Thank you for coming', or a disruptive 'Thank you, I think we've heard enough' displaying displeasure and frustration. To enhance the level of interactivity between the panel members, the actors were filmed together in a small room, and then a virtual audition room with black background was added using Adobe Illustrator (CS 5) and Photoshop (Figure 5.3). Similar to the recital simulation, a Flash interface was created to enable the panel to be manipulated using pre-set control commands from a computer console located in the backstage area.

The environmental cues in the audition simulation included CCTV footage displayed backstage of the panel chatting among themselves in hushed voices. On stage, there were spotlights, loudspeakers and curtains on both sides of the projected panel.

Measures

Simulation evaluation questionnaire A simulation evaluation questionnaire was based closely on work in surgical education by Kassab et al. (2011). It consists of 19 statements about (1) general perceptions and experience of performing in the simulator, (2) the quality of the backstage experience, (3) the quality of the onstage experience, and (4) the potential for using the simulator to develop performance skills. Each statement was rated on a 5-point Likert-type scale from 1='Strongly disagree' to 5='Strongly agree'. Table 5.1 shows all 19 statements, as well as descriptive statistics (mean, median, standard deviation) for each.

Figure 5.3: The virtual panel

Table 5.1: Descriptive statistics for questions in the Simulation Evaluation Questionnaire completed after performing in the recital and audition simulations. Rating for each statement were given from 1='Strongly disagree' to 5='Strongly agree'. The significance level p is shown for comparisons of the median rating for each question against a hypothesized median of 3, the scale mid-point, using the Wilcoxon signed-rank test.

Question	Recital				Audition			
	Median	Mean	*SD*	p	Median	Mean	*SD*	*p*
General perception and experience								
The simulation (including backstage, the audience, spot-lights, etc.) provided a realistic experience.	4.0	3.42	1.08	ns	4.0	3.67	0.50	0.005
The steps involved in the simulation (i.e., waiting backstage, walking on stage, etc.) closely approximated a real performance situation.	4.0	3.75	0.75	0.013	3.5	3.50	1.00	ns
I behaved and presented myself in the same way as I do in a real performance.	4.0	3.42	1.24	ns	4.0	3.67	0.98	0.046
Backstage								
The interaction with the backstage manager was realistic.	4.5	4.00	1.20	0.018	4.0	3.92	1.24	0.029
The CCTV footage in the backstage area was realistic.	3.0	2.83	1.40	ns	4.0	3.58	1.56	ns
The sounds heard in the backstage area were realistic.	3.5	3.42	1.08	ns	4.0	4.00	1.12	0.028
The decor of the backstage area (including signage and lighting) was realistic.	4.0	3.67	0.49	0.005	3.5	3.42	1.08	ns
On stage								
The transition from backstage on to stage was realistic.	4.0	4.08	0.90	0.008	4.0	3.67	0.98	0.046
The interaction with the audience in the performance space was realistic.	3.5	3.42	1.08	ns	3.5	3.42	1.08	ns
The spot-lights in the performance space were realistic.	4.5	4.08	1.08	0.012	3.5	3.42	1.37	ns
The curtains in the performance space were realistic.	3.0	3.33	0.98	ns	3.0	3.17	0.93	ns
Skill development								
The simulation could be used to enhance my musical skills.	4.0	4.25	0.86	0.005	4.0	4.25	0.75	0.004
The simulation could be used to enhance my technical skills.	5.0	4.33	0.98	0.005	4.5	4.33	0.77	0.004
The simulation could be used to enhance my communicative/presentational skills.	3.0	3.58	1.31	ns	4.0	4.17	0.83	0.006
The simulation could be used to help me manage performance anxiety and/or other performance problems.	4.0	4.17	0.93	0.007	4.0	4.33	0.77	0.003
The simulation could be used to highlight strengths in my performance.	4.5	4.33	0.88	0.004	4.0	4.17	0.71	0.004
The simulation could be used to highlight weaknesses in my performance.	4.5	4.25	0.88	0.006	4.5	4.42	0.66	0.003
I would recommend the simulation to people who are interested in developing/refining their performance skills.	5.0	4.33	1.10	0.005	4.5	4.42	0.66	0.003
I would recommend the simulation to people who are interested in teaching performance skills.	5.0	4.42	1.16	0.004	4.5	4.33	0.77	0.004

State anxiety inventory Immediately prior to each performance, participants were asked to complete Form Y1 (state anxiety) of the State-Trait Anxiety Inventory (Spielberger et al., 1983: for more details, see Chapters 3 & 4).

Electrocardiogram For the subset of 7 participants, ECG data were collected before and during performances in the real and simulated auditions using a wireless Zephyr Bioharness (for more details, see Chapter 4).

Procedure

For each performance, participants were asked to arrive 20-30 minutes before their scheduled performance time. They were shown to a 'green room' where they were fitted with the Bioharness (where applicable, n=7) and allowed to engage in their usual pre-performance routine (e.g., warming up, practicing, stretching, etc.). Stage calls were given by a member of the research team—acting as the 'backstage manager'—at 15 mins and 5 mins before the performance.

At 0 mins, each violinist was escorted to the backstage area, asked to complete Form Y1 of the STAI, and required to wait a further 5 mins while the backstage manager carried out a scripted check that the stage furniture was correctly placed, the auditorium lights were set, and the audience/audition panel was ready for the performance to begin. During this time, the backstage area was dimly lit, and the participants had sight of the relevant CCTV footage and could hear the low murmur of talking from the audience/audition panel. At the end of these scripted checks, the backstage manager turned to the performer, confirmed that she was ready to go on stage, opened the stage door for the musician to walk out, and triggered the applause from the audience (recital) or the greeting from the panel (audition).

While on stage, participants bowed (recital) or returned the greeting (audition) and started their performance as soon as they felt ready. As this was the first experiment using the simulator, polite (but neutral) reactions to the performances were set for the virtual audience and audition panel and no deliberate distractions (coughing, sneezing, talking, phone ringing, etc.) were interjected. Following the end of the performance and shortly into the audience's/panel's response, the stage door opened as a sign to the participant to exit the stage.

For the subset of 7 participants, an additional real audition was organized, in which the same procedure was followed. For parity with the simulated audition, three real panel members (two men, one woman) were shown the footage used in the simulated audition and instructed to provide the exact same neutral response (physically and orally) to all performances.

Performances for all participants were scheduled at the same time on separate days. The order of condition (i.e., simulated recital, simulated audition, real audition) was counterbalanced.

Data treatment and analysis

Simulation evaluation questionnaire Initial inspection of data from the simulation evaluation questionnaire revealed that 13 of the 19 questions did not meet the criterion for normality (Shapiro Wilk).[2] Therefore, responses to this questionnaire have been analysed using non-parametric tests (SPSS v19).

Electrocardiogram A key indicator of stress is the temporal fluctuation of the peak-to-peak times in the ECG—the R-to-R (RR) interval—known as heart rate variability (Berntson et al., 1997; Berntson & Cacioppo, 2004). This can be studied through time- or frequency-domain analyses. While the time domain can be characterized through a simple calculation of the mean R-R or its standard deviation, the frequency domain is studied using power spectral analysis examining heart rate variability's low frequency (LF) and high frequency (HF) components: $0.04 - 0.15$ Hz and $0.15 - 0.4$ Hz, respectively (Berntson & Cacioppo, 2004). Here, the ECG data were analyzed using MATLAB (R2013a).

[2]The Shapiro Wilk test assumes that the data does not show a symmetry of distribution of the data and includes 'outliers' that impact on the results using parametric test statistics (Field, 2008).

5.1.2 Results

Performing in the recital and audition simulations

For insight into participants' perceptions and experience of performing in the two simulations, the median rating for each item on the simulation evaluation questionnaire was compared against a hypothesized median of 3, the scale mid-point, using the one sample Wilcoxon signed-rank test (i.e., the non-parametric equivalent of the one-sample t-test). As shown in Table 5.1, the medians for all questions were either 3 or above, and the p values indicate that the medians were significantly higher than 3 for 12 of 19 statements for the recital simulation (63.2%) and 13 of 19 for the audition simulation (68.4%). With median values significantly higher than 3 on the majority of statements, these results suggest that both simulations offered a high quality, realistic performance experience, although with some variation between them.

Focusing more closely on the skill development statements, the participants reported strong potential for both simulations to be used to enhance their own learning and performance skills, to manage performance anxiety and/or other performance problems, and to teach these skills to others. Indeed, 7 of 8 statements for the recital simulation and 8 of 8 for the audition simulation were significantly greater than 3.

In terms of reported anxiety, participants' mean state anxiety score for the recital simulation was 35.09 (SD=11.09) and for the audition simulation was 34.09 (SD=7.09). According to Spielberger et al. (1983), moderate levels of anxiety are represented by scores of 36.47 (SD=10.02) for male students and 38.76 (SD=11.95) for female students. A paired samples t-test showed no significant difference between state anxiety scores across the two simulations ($t_{(10)}$=0.33; p>.05), suggesting that the average perceived anxiety before each simulated performance was comparable.

Performing in the simulated and real auditions

For the subset of 7 participants, the LF/HF ratio was calculated from the ECG for (1) the last 5 min of their 20-minute induction session (baseline), (2) 4 min immediately before their performance for the simulated and real auditions (pre-performance), and (3) their entire simulated and real auditions (performance). A repeated measures analysis of variance (ANOVA) was run with time of measurement (baseline vs. pre-performance vs. performance) and type of audition (simulated vs. real) as within-subjects variables.[3] The results indicate a significant effect of time ($F_{2,12}$=21.01; p<.001) and audition ($F_{1,6}$=9.94; p<.05) and a significant interaction between time and audition ($F_{2,12}$=8.28; p<.01). Inspection of Figure 5.4 suggests that these significant differences are mostly likely due to the high LF/HF ratio in the pre-performance period for the real audition. For levels of self-reported anxiety, participants' mean state anxiety score for the simulated audition was 32.29 (*SD*=7.39) and for the real audition was 37.43 (*SD*=7.09), suggesting moderate levels of perceived state anxiety (Spielberger et al., 1983). A paired samples t-test found no significant difference between state anxiety scores across the two auditions ($t_{(6)}$=-1.65; p>.05), suggesting that the average perceived anxiety before each audition was comparable.

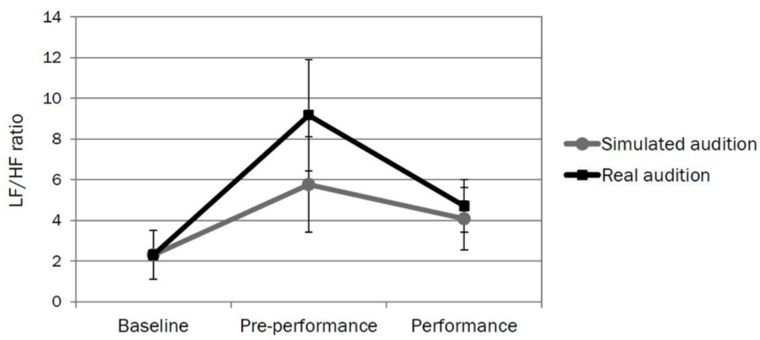


Figure 5.4: The CCTV footage and the virtual audience.

[3]The repeated measures ANOVA, or also called one-way ANOVA is applied for dependent groups who undergo an assessment at different time points. It is an extension of the t-test and looks at (significant) differences between means. The ANOVA requires and independent and and dependent variable which needs to be interval (or ratio) and ordinal, respectively.

5.2 Discussion

The aim of this study was to design, test, and explore the possible uses of two new distributed simulation environments for enhancing musicians' learning and performance. These included a small recital and audition setting, both of which offered key visual, auditory, and other environmental cues commonly found backstage and on stage at international performance venues, as well as scripted protocols for how musicians should be guided through them. The violinists found the simulations to be realistic and convincing, with all median ratings for statements in the simulation evaluation questionnaire at the scale midpoint or above (and a majority of statements rated significantly above). In terms of potential uses of the simulations, the musicians were clear in recognising their positive value for developing performance skills. Moreover, when examining participants' self-reported anxiety and physiological responses to performance stress in the simulated audition versus a real audition, there were no significant differences in state anxiety between the two conditions; while significant differences emerged in physiological responses for the pre-performance period, the direction of response (i.e., an increase in the LF/HF ratio) was the same for both, and there were no apparent differences during the performance. Reasons why the higher LF/HF ratio in the pre-performance period did not correspond to higher state anxiety scores could be manifold; musicians may experience the heightened physiological state which accompanies performance as either enabling or debilitating. Nonetheless, in this study comparable psychological and physiological responses were evoked across both auditions, real and simulated.

The distributed simulations used in this research drew upon a selective abstraction of salient procedural and environmental features. In both cases, an important element was the 'backstage manager,' who guided each musician through the scripted performance process and served as the gatekeeper for their transitions on and off the stage. The recital simulation benefitted particularly from the decor of the backstage area, including signage and lighting, as well as spot-lights in the performance space, while the simulated audition was enhanced especially by auditory cues played in the backstage area.

Unlike previous research in music (Bissonnette et al., 2015; Orman, 2003, 2004), which focused on exposure to virtual environments as a means of managing performance anxiety, our results suggest that simulation training may offer wide ranging benefits for musical learning and performance. While further studies are needed to establish these benefits objectively, feedback elicited as part of the simulation evaluation questionnaire suggests that the simulations provided a path by which musicians could not only highlight their performance strengths but also address their weaknesses. As such, they were seen as potentially useful tools for teaching musical skills more efficiently. More generally, this research adds to the growing literature demonstrating that virtual environments can effectively aid learning, especially as they can be accessed repeatedly and consistently, at controlled levels of risk and with pre-defined outcomes. The extent to which the effectiveness of the present simulations will persist through repeated exposure remains to be tested, but findings from other domains would suggest that the prospects of using virtual environments repeatedly and longitudinally to enhance learning and performing are indeed promising (Rothbaum, Hodges, Smith, Lee, & Price, 2000).

Rothbaum et al. (2000) assigned patients suffering from fear of flying to VR, standard treatment, and a wait-list control. The VR was displayed by a head-mounted display with stereo earphones. Eight group sessions (max. 5 patients) led by a behavioural therapist were conducted, including four sessions of anxiety management training followed by four sessions in either the VR or the standard treatment scenario. In the VR sessions, patients were asked to sit in an airplane and experience simulated take-offs as well as landings during either calm or stormy weather conditions. For the standard treatment, stimuli were presented such as ticketing, trains, parked planes, and waiting area, including imagined exposure (i.e., imagining take-offs, cruising, landing, etc.). All sessions were conducted within 6 weeks, followed by a post-test and a follow-up assessment based on standardised questionnaires. Again, the results demonstrated an equally superior effect of the VR and standard treatment compared to the control group as well as the maintenance of reduced anxiety after 6 months.

Also, Anderson et al. (2013) assigned patients suffering from social anxiety (public speaking) to either a VR or in-vivo exposure. The virtual reality display using a head mounted display encompassed: (1) a public speech in a virtual conference room; (2) a classroom; and (3) virtual auditorium. A therapist controlled a variety of different audience responses (e.g., interested, bored, supportive, hostile, distracted) and guided the participant through each step. In the in-vivo exposure therapy patients were asked to give a videotaped presentation in front of an evaluative audience. A pre-test, post-test and a 12-month follow-up assessment were carried out and after 8 sessions lasting between 20 and 120 minutes, outcomes of the virtual reality and the in-vivo exposure were equally significantly improved compared to the control group.

Emmelkamp, Krijn, Hulsbosch, and de Vries (2002), for example, investigated the use of a VR in treating patients with acrophobia (fear of heights). The authors randomly assigned patients to either a virtual reality display or in-vivo-exposure, which is a direct confrontation with the feared object. The VR consisted of a low-budget environment, encompassing a dark room, a railing the user could hold on to, and a visual and auditory display aiming to recreate a feeling of height. After a first familiarization, three gradually increased anxiety-inducing scenarios were presented: a mall, four floors high; a fire escape up to approximately 50 feet; and a roof garden up to approximately 65 feet. In the in-vivo exposure the participants were exposed to the same environments. In all scenarios, a behavioural psychologist controlled the setting and guided the participant through each scenario until habituation set in. The results—based on standardised questionnaire measures—demonstrated a significant, yet equally effective decrease in all measures after both the VR and the in-vivo-exposure, with the decreased anxiety remaining up until 6 months. This study has focused on responses to simulated recital and audition scenarios with relatively neutral and 'well behaved' virtual observers. Subsequent studies should examine the influence of disruptions and distractions (e.g., coughing, sneezing, phone ringing), as well as more positive and negative observer responses. They should also consider recruiting larger samples of musicians, who can specifically be studied in low and high anxiety groups. In addition, there is scope for building and testing further simulated environments: from changing audience size or modifying the number and type of environmental features to involving more performers or altering the performance task itself. It would also be instructive to test whether the degree of background knowledge about the development of the simulations or prior knowledge of whether the performer will encounter a real or virtual audience before they enter the stage (i.e., a blind experiment) would impact how musicians perceive and interact with each simulation.

In general terms, one could argue that distributed simulation training, as employed in this study, has much to offer musicians. However, difficulty arises in mapping out precisely how to use simulation in ways that are meaningful to those at different levels of skill, with varying degrees and types of performance exposure, and with very personal experiences of performance anxiety symptoms. Further experimental work that systematically addresses these parameters, carried out using psychophysiological and questionnaire-based measures extended from the current study, could provide such insight.

In this respect, subsequent investigations are needed that explore both generalisable and individual-specific benefits of simulation training. Research should systematically test the effects of simulation on skill acquisition, planning and self-regulatory strategies, and techniques for improving communication and presentational skills, alongside interventions for managing anxiety. It should also investigate how to match certain types, lengths, and intensities of training to individual musicians' learning and performance objectives. When on stage, it is precisely these objectives that distinguish one performance from another.

6 | Musicians' perceptions of using simulation training

6.1 Introduction

Current performance training often strives to deliver a holistic framework that enhances musicians' performance confidence[1] and creates a positive performance experience (Liertz, 2007). Some of the most innovative approaches directly address aspects such as musicians' self-efficacy (Bandura & Locke, 2003), stage presence (Davidson, 2012), and an increased sense of control over the performance situation, in particular the employment of performance facilitating thoughts (Clark, Lisboa, & Williamon, 2014). In order to improve musicians' performance outcomes and help them manage the challenges of performing, a wide variety of strategies and techniques are now being applied within the musical domain and tested internationally (Kenny, 2011), including cognitive-behavioural interventions and mental skills training and biofeedback (Braden, Osborne, & Wilson, 2015; Clark & Williamon, 2011; Gruzelier & Egner, 2004; Rodebaugh & Chambless, 2004; Thurber, Bodenhammer-Davis, Johnson, Chesky, & Chandler, 2010). While there is evidence that these are effective (Kenny, 2005; Williamon, 2004), they are typically experienced and practiced some distance away from the venues and situations in which performance actually occurs. To a large degree, effective performance training should allow musicians access to and experience of performance in the real world (Kassab et al., 2011). Taking this into

[1] According to Sander and Sanders (2003), confidence is characterised by '... [a] strong belief, sure expectations [and] having no fear of failure' (p. 1).

account, music educators are now beginning to experiment with simulation as a complementary training tool, where virtual reality (VR) components are interwoven alongside key features of real performance environments so that '... a person can move around and interact as if he actually were in this imaginary place' (Satava, 1993, p. 203).

Simulation training has been applied successfully in a wide range of fields, including (clinical) psychology (Krijn et al., 2004; Safir, Wallach, & Bar-Zvi, 2012), medicine (Selvander & Asman, 2012) and sport (Zinchenko, Menshikova, Chernorizov, & Voiskounsky, 2011), addressing anxiety related problems. Across these domains, in particular the relationship between anxiety and perceptual-motor performance in response to demanding performance conditions (e.g., critical surgical procedures) has been put under scrutiny. Anxiety can have detrimental effects on performance execution, attention and decision-making, which is expressed in an increased likelihood to experience and perceive the environment as threatening, to focus on task-irrelevant information (i.e., attentionial bias) and to display threat-related behaviour that may interfere with the overall performance (outcome: Nieuwenhuys & Oudejans, 2012). Simulation training offers an evaluation of these effects in a consistent performance setting that is less exposed to situational variability, therefore providing an ideal tool for educational and interventional assessments (Scalese, Obeso, & Issenberg, 2008).

To put this into context, Emmelkamp et al. (2002) exposed patients suffering from acrophobia either to a simulation (generated by a dark room, a virtual display, and surrounding audio to create the feeling of height) or to in-vivo-exposure to high places. Self-reports of anxiety and behavioural avoidance were measured before and after exposure, and compared with the in-vivo-exposure, the results showed a significant decrease in both measures after simulation training. Simulations have also been used to train elite performers of many types, from athletes and pilots to surgeons, where there are limited possibilities to train specific skills in real-life conditions (Kassab et al., 2011; Le, Adatia, & Lam, 2011; Lendvay et al., 2013). Kassab et al. (2011), for example, demonstrated a significant improvement in surgeons' abilities to perform a laparoscopic cholecystectomy using simulation compared with standard training tools, and they showed that surgeons felt as confident of operating afterwards as if exposed to real scenarios. In their study, they explored the face, content and construct validity of their newly developed Distributed Simulation (DS). Ten novice as well as expert surgeons were asked to perform a medical procedure in the simulation and on a box trainer. While the face and content validity were developed to address the question of perceived realism and skill demonstration, the construct validity was evaluated by the Objective Structured Assessment of Technical Skills (OSATS: Undre, Sevdalis, Healey, Darzi, & Vincent, 2007), which evaluated the behaviour in operating theatre team-members (communication, leadership, monitoring and others within and between nurses, surgeons and anaesthetists) by means of an external observer. The results showed that both groups perceived the DS as realistic, with experts performed at a higher level of expertise than novices (i.e., construct validity). The experts had also the feeling that they can behave as if in a real-life environment, suggesting that the DS is an ideal tool to practice and enhance specific performance skills.

In music, studies have first tested the use of simulation in managing performance anxiety. Orman (2003) and Orman (2004) asked eight saxophonists to perform in public (for peers) and in front of virtual scenarios using a head-mounted display, inducing different degrees of anxiety such as an empty room versus an audience. Self-reports of anxiety were taken before, during, and after the performance, while heart rate was monitored throughout. The results were inconclusive, with no consistent patterns of change in either self-reported anxiety levels or heart rate as a function of exposure to the simulated performance situations. In another study, Bissonnette et al. (2015) asked seventeen pianists and guitarists to take part in simulation training that included exposure to a VR display recreating a concert audience on a large screen and immersive ambient sound and stage lighting. They found a significant decrease in self-reported state anxiety for high trait anxious female musicians from before to after the exposure, although no significant decline in state anxiety for men or women with moderate to low trait anxiety (for more details of each study, see Chapter 5).

More recently, I examined musicians' ratings of their experiences while performing in simulated recital and audition situations (Williamon et al., 2014: see Chapter 5). I also examined self-reported state anxiety and heart rate variability in the simulated audition performances compared with corresponding real auditions. The simulations were created in a specially designed performance space that included abstractions of key features found in recital and audition environments, such as a waiting area (backstage) with a backstage manager and CCTV footage and a performance area (on-stage) with a piano, spotlights, and curtains. The virtual interactive audience and audition panel were programmed to respond positively, negatively, or neutrally, controlled directly from the backstage area. Overwhelmingly, the musicians rated both the recital and audition simulations as useful tools for developing and refining their performance skills. Furthermore, there were no significant differences in state anxiety or heart rate variability between the simulated auditions and the real auditions, suggesting that the simulation was able to evoke similar experiences and stress responses (psychologically and physiologically) as a real performance situation.

Although these studies offer first insight into the uses and utility of simulation training in the musical domain, a thorough investigation of how musicians experience—or may come to experience—simulation training has yet to be conducted. Understanding musicians' experiences in this relatively new field is essential in terms of informing the potential and effectiveness of simulation for facilitating musical learning and performance. The aim of this study, therefore, was to understand holistically how musicians' experience two simulated performances: a recital and an audition. Both have distinctive qualities and are typical to a musicians' performing career; while the recital provides a more performer-supported environment where musicians are likely to receive positive reinforcement at the end of their playing (i.e., audience applause), auditioning is highly competitive, often with little immediate feedback, and characterised by expectations of the highest quality musical, technical and sight-reading abilities.

Our overarching research question sought to understand: *How do conservatoire students experience simulation training?* Informed by the literature, this question comprised two main areas of enquiry. Firstly, *to what extent is simulation training immersive for musicians, as compared with real-life performances?* Studies have shown that the degree of emotional involvement during simulation training depends on personal expectations and the technology used (Mazuryk & Gervautz, 1996; Price & Anderson, 2007), and it directly impacts on the degree of 'presence'

(Schubert, Friedmann, & Regenbrecht, 2001), which is the subjective experience of being in one place or environment, even when one is physically situated in another' (Witmer & Singer, 1998, p. 225). In other words, the more immersed students feel during the simulation training, the more likely they are to 'overlook' and 'neglect' its artificial construct, thus allowing them to experience simulation training similar to real-life situations. Secondly, this study set out to understand the characteristics of the musical simulation reported to facilitate (or not) immersive experience; in other words, *to what extent is simulation training experienced as a tool for improving specific performance skills and tackling performance-related anxiety problems?* Thus far, simulation training has been applied in a wide range of domains to either enhance specific performance skills (Clayton et al., 2013; Kassab et al., 2011) or to reduce symptoms associated with (performance) anxiety (Bissonnette et al., 2015; Morina, Brinkman, Hartanto, & Emmelkamp, 2014). Considering research executed in the musical domain, however, simulation training has only been validated alongside anxiety reducing protocols (Bissonnette et al., 2015) rather than performance enhancement strategies. With this in mind, this study set out to examine musicians' experiences of simulation training as a tool to enhance performance, reduce performance-related anxiety, or both.

6.1.1 Method

Participants

Nine of eleven undergraduate music students enrolled on an optional performance psychology module at the Royal College of Music agreed to take part in the study. The students were all women, 21.33 (*SD*=0.81) years old, and studied the following instruments: clarinet, oboe, piano, recorder and voice. On average, they first performed at the age of 6.66 years (*SD*=1.50), practised 4.50 hours per day (*SD*=1.18), and performed in public 3.08 (*SD*=2.01) times over the month preceding the study. The research was conducted according to ethical guidelines of the British Psychological Society, and informed consent was obtained from all participants.

Procedure and data collection

Participants were allotted a specific performance time and asked to attend at least 10 min beforehand for warm-up in a designated space. They were then called to the backstage area by a backstage manager where they waited quietly for approximately 2 min before receiving the signal to enter the stage area. At that point, they performed a 2-min unaccompanied piece of their choice in front of either the virtual audience or the virtual audition panel; extended descriptions of each simulation, see Chapter 6. For the audience, a neutral applause was provided, followed by listening behaviours similar to those of a typical Western classical performance (e.g., naturalistic body swaying and discrete fidgeting and movement). For the audition panel, a neutral introduction was given (i.e., 'Hello, please start whenever you are ready'), followed by typical evaluative behaviours such as making notes and leaning back while simultaneously portraying a neutral facial expression. After the performance, the audience applauded politely, while the audition panel gave a polite but noncommittal 'Thank you very much'. The order of the two performances was counterbalanced, and all performances were audio and video recorded for the participants' own use.

Participants were asked to perform a two-minute unaccompanied piece of free choice in the RCM simulation. Participants performed twice, once in front of the virtual audience and once in front of the virtual audition panel. For the audience, a neutral applause was provided, followed by listening behaviours similar to those of a typical Western classical performance (e.g., naturalistic body swaying, fidgeting, and movements). For the audition panel a neutral 'Hello, please start whenever you are ready' introduction was given, followed by typical evaluative behaviour such as making notes, leaning back while simultaneously portraying a neutral facial expression, and behavioural feedback. After the performance, the audience replied with polite applause, while the audition panel gave a polite but noncommittal 'Thank you very much'. The order of performances were counterbalanced and audio and video recorded for the participants' own use.

After the two performances, qualitative data were collected through (1) a focus group interview and (2) individual written reflective commentaries, both with all nine participants.

The focus group was carried out directly after the simulation training in order to capture student's spontaneous reflections on their experience, while the commentaries were written weeks after the simulations to allow for a retrospective reflection. Ideally, such interviews should be as loosely structured as possible (Krueger & Casey, 2000), and in this study, the moderator, along with two assistants operating as quiet observers, asked open-ended questions about the musicians' expectations of using the simulations, their experiences of using them, suggestions for improvements to the facility and to the procedure, what they learned from performing in the simulations, and the potential uses of simulation training in music education (Table 6.1). Participants were encouraged to answer in as much detail as possible, and the discussion was audio recorded and transcribed by a member of the research team.

Table 6.1: Schedule for the focus group interview.

Domain	*Questions*	*Further exploration*
General expectations of the simulations	What did you expect from the simulations?	Recital simulation Audition simulation
General and specific experiences of performing in the simulations	How would you describe your experiences in the simulations?	How did you feel before? How did you feel during? How did you feel after? What did you notice about each simulation? What is your strongest memory of the performance in each simulation?
Suggestions for improvements	How would you improve in the simulation experience?	The facility: real and virtual components & the procedure
Reflections on experiences and implications for performance training	What have you learned from your performances in each simulation?	Training performance skills: stage presence, communication, other Managing performance stress and anxiety Uses of simulation training in music education

In addition, based on their experiences of performing, the musicians were asked to write a 1,500-word reflective commentary as part of their assessment for the undergraduate module. The structure of the commentary was open for the student to determine, but they were required, as per the module syllabus, to focus on what they expected of the simulation training, their experiences of the two simulations (including how effective they felt it to be as a performance platform relative to live performance and any differences between playing to a virtual audience and audition panel), and what they learned from the experience. The musicians gave informed consent for their written course work to be included in the research, and the research team were not involved in assessing the submissions.

Data analysis

The data of the focus group interview and the reflective commentaries were combined and analysed using NVivo10 (Onwuegbuzie et al., 2010). The focus group interview data was transcribed by the first author and the reflective commentaries were closely examined several times by both the first and second author before meaningful phrases, ideas, and concepts were identified and compared between and within participants. These were then labelled and grouped into a series of sub-themes that characterised the musicians' experiences of the simulations, clustered together into emergent themes (Bernard & Ryan, 2010; Krueger & Casey, 2000). Themes and sub-themes were discussed between the first and second author throughout the data analysis (Clark et al., 2014). In what follows, the main features of each theme are introduced, supported by indicative evidence from the data and related where appropriate to existing literature. To assure anonymity, participants are numbered 1-9, and the source of information (focus group or reflective commentary) is indicated by FG and RC, respectively. The transcript of the focus group interview is given in the Appendix.

6.1.2 Results and Discussion

Based on the analysis of the focus group interview and the reflective commentaries, four main themes emerged (see Figure 6.1): (1) the anticipation of using the simulations, including expressions of nervousness and scepticism but also intrigue and hope; (2) the process of performing in the simulations, such as the transition between the backstage and on-stage areas, the available auditory and visual cues, the experiences of performing for the audience and audition panel, and the degree of interaction between the performer and the virtual displays; (3) the usefulness of simulation as a tool for developing music performance skills, discussing the advantage to have a 'safe space' to present and evaluate skills; and (4) ways of improving simulation training, emphasising the potential for enhancing the current performance procedure and facilities, such as the waiting time in the backstage area and the performance space on-stage, and using simulation alongside other interventions such as biofeedback and mental skills training.

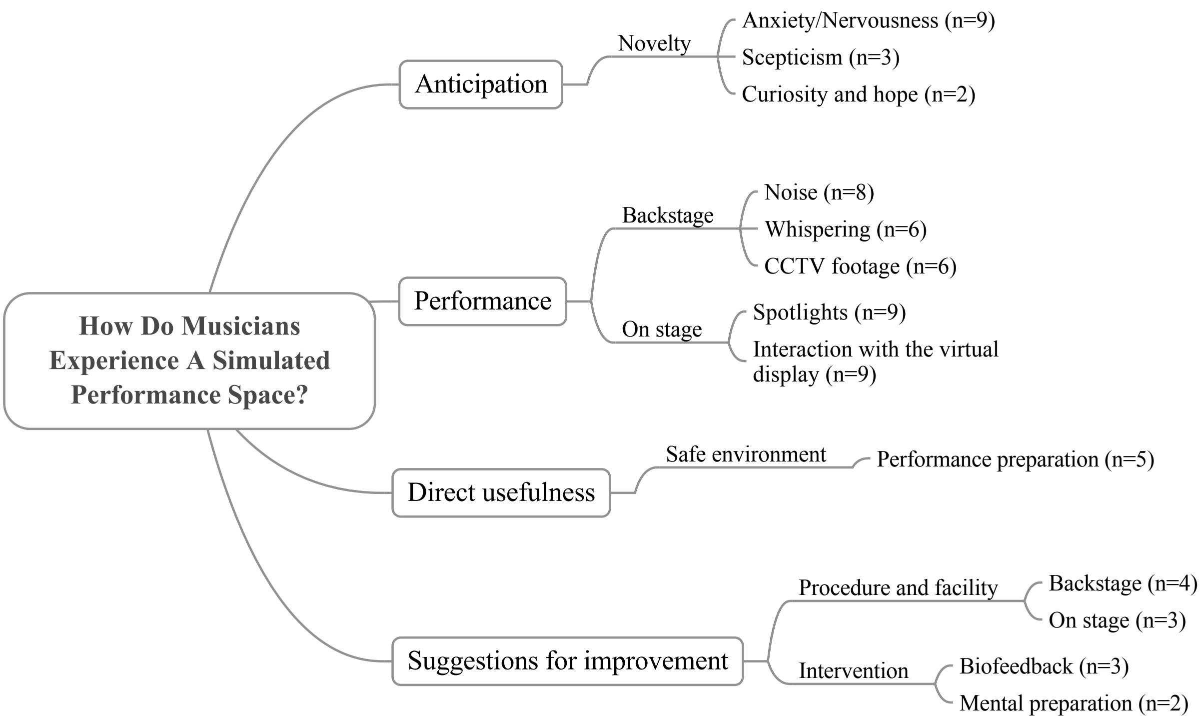


Figure 6.1: Themes, subthemes, and frequencies emerging from the qualitative analysis.

The anticipation of using the simulations

The musicians taking part in the study had not previously performed in simulated environments, and anticipation of doing so resulted in four main feelings of anticipation of the first performance: anxiety, scepticism, curiosity and hope.

Anxiety Similar to a live performance, the musicians experienced feelings of apprehension prior to entering both simulations.

> I started experiencing some anxiety a few hours before the first session began. (RC 3)
>
> I was slightly nervous in anticipation. (RC 1)
>
> It was scarier than I thought it would be. (FG 1)
>
> To my surprise, I felt quite nervous waiting outside of the room. (RC 9)
>
> I thought this simulation was going to be fun. Then I got there, and I got nervous. (FG 2)

Feelings of anxiety or nervousness are common pre-performance experiences and have been related to musicians' personality and past performance experiences (Kenny, 2011). Here, these feelings appeared to emerge mostly in reference to the novelty of the situation, the fact that the students did not know what to expect from the simulations, and the impact of arriving and waiting outside the performance space. Studies have shown that the pre-performance period can have a pronounced impact on musicians' physiological reactivity to stress (e.g., Abel & Larkin, 1990), and demonstrated that it was the anticipation of performing that caused the highest reactivity among musicians, a finding lent support by the current study.

Scepticism The musicians also declared feelings of scepticism and doubt about whether the simulations would be truly immersive and realistic.

> Because I knew it was just a simulation, I thought it was not going to feel that real. So I was a bit unsure. (FG 2)
>
> I was sceptical of the simulator initially and how effective it would be. (RC 4)
>
> I expected it to have less effect on me than it [actually] did. (FG 2)

Similar to the feeling of anxiety, scepticism arises alongside a general reluctance to facing something unknown (Millar, 2011). The musicians expressed scepticism in terms of the effectiveness of the simulations, in particular how realistic the performance experience would be compared with a real performance and how it might, mentally and physically, affect them as performers.

Curiosity and hope Curiosity and hope are viewed as positive qualities, characterised by an eagerness to explore, investigate, and learn something new. Both, furthermore, facilitate psychological growth, self-discovery, and creativity (Ofer & Durban, 1999). The musicians were certainly curious and expressed hope about the new experience of performing in the simulations.

> I was curious about what it would entail and how it would work. (RC 5)
>
> I was intrigued as to whether or not I would feel as if I was walking onto a real stage, and wondered whether I would get nervous at all despite being aware that it was not a 'real' situation. (RC 2)

The musicians expressed curiosity either in terms of the performance environment itself or the effect that the simulations may elicit. Comparisons were drawn to the musicians' real performance experiences, as well as whether they were able to engage fully with the simulations. More specifically, they expressed hope for a tool that could recreate performance experiences similar to real performance settings.

> I was not convinced that the experience would impact me in the same way that live performances do. Nonetheless, I hoped it would! (RC 5)
>
> I had high hopes for the performance simulator. (RC 3)

The musicians' comments highlight the desire of having a training tool that has been shown to be effective in other domains. They demonstrated a general open-mindedness towards new training approaches, a feature that is crucial to allow an immersive and successful experience in simulation (Murray, Fox, & Pettifer, 2007).

Overall, the anticipation towards using the simulations was expressed by feelings of anxiety, scepticism, but also curiosity and hope. The way musicians normally await a performance and the subsequent success of that performance typically depends on the employment of either facilitating or debilitating thoughts (Clark et al., 2014). In this study, the musicians' expression of emotion varied—perhaps reflecting the novelty of the simulation experience—but included anxiety similar to that felt in real performances. However, these diverse feelings during the anticipatory period positively changed once the musicians entered the simulated performance space, with their first hands-on experience of what it actually means to perform in a simulation and in front of virtual displays.

The process of performing in the simulations

The musicians' experiences of performing in the simulations were categorised according to the different stages in the performance process, focusing first on the backstage area and then on the stage area.

Backstage The experience of waiting in the backstage area evoked performance anxiety symptoms including fidgety behaviour and elevated heart rate.

> I was surprised that just seeing the screen with the audition panel in the backstage area was enough to trigger the usual anxiety I get before a performance. Typically I feel slightly nauseous. . . and start fidgeting or feel shaky. (RC 3)
>
> Before going on stage, [the backstage manager] was whispering to me, and I thought 'is this actually a performance?' [laughter] (FG 4)
>
> I had that backstage feeling. (FG 5)
>
> The backstage feeling was surprisingly real. It was dark, [the backstage manager] was whispering, and I could hear the audience murmuring and moving. My heart started pounding. I did not know what lay on the other side of the wall. (RC 6)

The symptoms described here were primed specifically by the backstage environment, including the inclusion of pre-filmed (fake) CCTV footage of the performance space and background noise such as whispering and murmuring from the audience and audition panel. It also gave rise to a feeling of uncertainty of what was going on through the stage door. An increased feeling of realism was added by presence of the backstage manager, who acted out a scripted role of liaising with the front-of-house and who coordinated the transition from backstage to the stage area.

On stage Authentic simulations depend on realistic auditory and visual cues to achieve a feeling of immersion (Morina et al., 2014; Murray et al., 2007). The main points mentioned by the musicians in this study centred on the spotlights that were directed at them immediately upon their entrance on to stage.

> The spotlight was one of the first elements I noticed, and it surprised me. They gave me a full feeling of actually being on stage. (RC 1)
>
> To play with this unusual kind of lighting added a bit more pressure to the musical performance in situ, as the whole experience felt a lot more real. (RC 5)
>
> I felt nervous when I saw the spotlights. (FG 2)

The use of spotlights generated a feeling of sudden surprise, an immediate increase of pressure, as well as nervousness. Thus, the musicians appeared to experience feelings similar to those of a real performance, leading to an increased perception of authenticity.

Interaction with the virtual display In research into virtual reality, the feeling of 'presence' (i.e., an increased ability to 'overlook' or 'neglect' the knowledge of the virtual components) depends on the graphical reality and interactivity of the technology used, as well as one's willingness to engage fully with it (Sas & O'Hare, 2002). Interactivity and related feedback should be 'prompt, fluent and synchronised' and, ideally, highly synchronised within and between different modalities (Mazuryk & Gervautz, 1996, p. 18). The musicians focused particularly on their interaction with the virtual displays and the human-like appearance and behaviour of the audience and audition panel.

> I wasn't really expecting that kind of real situation... You know, with [the audience] actually moving... it made me feel more like they were human even though they were not. (RC 9)
>
> With the audition panel, I felt connected. They spoke to me, and I felt like I should speak back. (FG 3)
>
> The fact that the audition panel was interactive made the first session very genuine. (RC 5)

It seems that the musicians were not expecting the virtual display to interact with them before, during or after their performance and that even basic interactions between performer and the virtual displays enhanced the reality of the simulations.

According to the wider literature on simulation, adequate sensory feedback should consider the relevance of the sensations of vision, audition, touch, smell and taste (Downtown & Leedham, 1991); in addition, the virtual reality components should be synchronised and exhibit marginal latency effects with the user's behaviour (Sherman & Craig, 2003). As in this study, simulation designs in other fields have also been able to provide these cues effectively, without the need for elaborate motion tracking systems (Mazuryk & Gervautz, 1996).

Usefulness of simulation as a tool for developing music performance skills

The musicians identified one prevailing way in which the simulations were directly useful to their own practice: the generation of a safe environment to train and to practise performing.

Safe environment Simulated performance spaces have been classified as 'safe' environments—that is, they are potentially less harmful than in-vivo desensitization exposure, while offering a more tangible and real approach than cognitive therapies using imaginal desensitization (North, North, & Coble, 1997). The musicians in this study confirmed that the simulator was a relatively safe space in which to practice performance.

> The simulator could potentially serve as a platform that provides the necessary safe space to acquire performance skills through trial and error. (RC 9)
>
> [It is a] safe environment knowing that no one is there. (FG 4)
>
> Waiting for an exam where one will be judged and criticized is much less often experienced than the hours spent in the practice room and is, therefore, more likely to throw one off balance before a performance. This is where simulation can help overcome this fear, by repeated exposure in a safe and controlled environment. (RC 8)

Students emphasized this benefit in terms of having a space in which the fear of failure is reduced through the elimination of negative appraisal that may come from real audiences and evaluators. Additionally, the simulations allowed for experimentation and skill development through a process of trial and error iteration. The musicians also acknowledged the possibility of using repeated exposure to overcome problems such as performance anxiety and to prepare them physically and mentally for real performance experiences, be they positive or negative.

Reflection on performance is an indispensable part of performance enhancement (MacNamara, Button, & Collins, 2010). Rather than a standard practice room and a distressing real stage, simulation training provides a halfway approach that comes closer to real performance than the former and is more accessible and less risky than the latter. Performance training where musicians are encouraged to behave as they would in a real performance setting offers greater scope to build upon strengths and to address weaknesses in performance, such as improving stage presence without having to suffer career threatening failures or other negative consequences.

Ways of improving simulation training

The final theme stresses the potential that the musicians identified to enhance the simulations, focusing on the procedure and facility, as well as the prospects for simulation training to improve music education more generally.

Procedure and facility The importance of sensory feedback in simulations to create an authentic performance experience has been addressed extensively (Sherman & Craig, 2003). Less, however, has been written on how the simulation facility (e.g., the room and furniture) and the procedures by which simulations are accessed can be tailored to the specific field of use. In this study, the musicians pointed to the need for a longer waiting time in the backstage area and a more spacious performance area on stage.

> I felt there needed to be longer wait before the performance to replicate real life. (RC 9)
>
> Increase the time spent in the backstage area. Personally, I find that the longer I have to wait, the more nervous I get. (RC 7)
>
> Sometimes you have to wait around a while before you go on, and this time, for me it was quick. (FG 3)
>
> The bit where I get nervous is when I have to wait. (FG 5)

The points raised draw attention to the disparity between the musicians' experiences of real performances and those in the simulations, notably with regard to the amount of time spent waiting in the backstage area (i.e., in this study, just 2 mins). Another point was the small size of the room in which the simulations are currently housed:

> The lack of space in the room did not pose any problems during the audition simulation, since auditions are held in a variety of venues. However, this had a large impact on my experience of the recital simulation. (RC 4)
>
> I would make sure that the size of room used is a larger performance space. (RC 6)
>
> It would be useful if the room was bigger because... we do not perform in little spaces. When the stage is bigger, you feel exposed. (FG 2)

The restricted stage area was noticed particularly in the recital simulation, which in a real performance setting would be more spacious than in the simulation space. This was not, however, a problem for the performances in the audition simulation, as auditions can occur in smaller rooms.

Intervention Finally, the participants highlighted the potential for the simulations to be used as a form of intervention, to help musicians overcome challenges and manage anxieties that can impair performance quality.

> It would be interesting to see which thoughts and emotions would keep, for instance, our heart rate at a slower level. Maybe then we musicians could finally train ourselves to be fully prepared for performance. (RC 3)
>
> As an example, it would be very useful to perform in the simulations with a particularly distracting and difficult virtual audience to prepare us for all eventualities that may occur in a performance. (RC 2)
>
> I think 'okay, I can do that', and then if something happens in a real life situation when I might not expect it. . . it's fine because I have experienced it before. It's about having the right mental state. (FG 5)

The musicians' suggested the use of training emotional regulation by means of a gradual increase of distraction caused by the virtual display. In addition, they suggested that simulation training could be usefully paired with other performance enhancement interventions in order to optimise physical and mental responses to performance situations. Indeed, research has shown that interventions such as biofeedback and mental skills training can directly improve performance quality and anxiety management skills (Arora et al., 2011; Gruzelier & Egner, 2004; Thurber et al., 2010). For instance, recent studies that addressed the efficacy of mental reparation in the musical domain stems from Highben and Palmer (2004). They asked sixteen pianists to mentally rehearse four novel 20-minute pieces over ten practice trials. The practice trials included: (1) normal practice; (2) practice without auditory feedback (sound turned off but still pressing the keys); (3) practice without motor feedback (not pressing the keys but hearing a recording of the piece); and (4) mental practice in the absence of auditory and mental feedback. Results showed that the removal of any feedback lowered learning and memory abilities, and that normal practice provided the most efficient performance outcome. In addition, pianists who possessed greater aural skills were less affected by the missing feedback during practice than those without. However, due to the cost of accessing real concert halls, these techniques are often applied away from the contexts in which performances take place. Simulation opens entirely new modes of delivery for such interventions, allowing researchers and practitioners to put them to the test by applying them in the situations where they are most needed.

6.2 General Discussion

In respect to the study's research question and areas of enquiry, the results demonstrate that: (1) while students' level of immersion in simulation training differed, context and environment contributed to an immersive experience, enhanced through the use of key auditory and visual cues such as background noise and spotlights, as well as the degree of interaction with the virtual displays; (2) the musicians acknowledged the safety available in simulation training and its potential for developing, experimenting with and enhancing a wide range of performance skills, rather than reducing performance-related anxiety.

Effective simulations should provide adequate sensory feedback and graphical reality which should both be displayed precisely and with low time latency (Mazuryk & Gervautz, 1996). The simulation training in this study was able to present realistic visual and auditory feedback to an extent that allowed the majority of students to experience some feeling of immersion. Immersion experiences in this study were enhanced by auditory and visual cues (background noise and spotlights), and the interaction with the virtual audience and audition panel as well as a combination of high-resolution human computer interface and prompt and fluent feedback, synchronised within and between different modalities (e.g., visual and auditory feedback).

The musicians' preference to use simulation training to enhance specific performance skills, rather than to reduce performance anxiety, is a new finding not previously observed in studies using simulation (Bissonnette et al., 2015; Orman, 2003, 2004). While the training may indeed be able to reduce performance anxiety, the results of this study expand the potential of simulation training as a tool to acquire and practice specific performance skills, providing more options for optimising preparation for (high-pressure) performances of all types. Future studies are therefore encouraged to elaborate on these findings by considering exactly how simulation training may be employed for the development of widely defined musical, technical and communicative performance skills.

This study offers implications for practice, identifying several areas in which student experience can be enhanced and therefore the effectiveness of simulation training improved. The results provide evidence that students experience simulation training as an opportunity to strengthen positive attitudes towards the preparation, delivery and review of performance, reporting an interest in simulation training as an intervention to facilitate a deeper awareness of the physical and psychological processes underpinning successful performances. To this end, simulation training may be provided alongside real-life feedback of musicians' physical and psychological responses (e.g., heart rate, breathing, state anxiety) before, during and after their performances in order to facilitate increased performance awareness while practising performing in a relatively safe and low-exposure performance environment. Similarly, students emphasised using simulation training in combination with mental preparation strategies. Indeed, recent research has shown that elite musicians under high-stress performance scenarios particularly focus on positive thinking and self-talk in order to build up sufficient performance confidence (Buma, Bakker, & Oudejans, 2015). This was, for instance, shown by Buma et al. (2015), who conducted systematic research in oder to understand the attention needed when performing under high-pressure performance situations. To find out more about how and to what extent to what musicians' employ performance coping strategies, they asked elite musicians to provide a report on what they focus on an think about during moments of pressure. Through the application of retrospective methods such as concept mapping and verbal reports, the authors alongside seven expert teachers generated a cluster analysis. The results lead to six clusters of which three clusters, namely 'focus on physical aspects,' 'thoughts that give confidence,' and 'music-related focus' accounted for 85.2% of the 190 statements created and drawn from the verbal reports. The authors conclude that in order to develop and maintain a high quality performance under pressure, musicians focused on aspects such as music-related information, physical features and thoughts that would provide them with some sort of performance confidence.

During mental rehearsal, musicians are encouraged to apply aural, visual, and kinaesthetic visualisation, as well as cognitive and motivational strategies (emotional regulation) that are believed to lead to a performance sensation similar to a real (and ideal) performance (Connolly & Williamon, 2004). The benefits of mental skills training was, for instance, shown by Bernardi, Schoris, Jabusch, Colombo, and Altenmüller (2013), who assessed mental practice and musicians' progress on music memorisation using mental practice strategies of individually preference. Sixteen pianists were asked to memorise two pieces by applying either physical practice or mental practice. Performances were evaluated in terms of correctness of notes, articulation and phrasing, dynamics and expressions, and via a global performance quality score. Results showed an improved musical learning using mental practice as well as mental practice alongside physical practice, which was also supported by the external performance quality ratings.

Future work should, therefore, address these points by developing new protocols for mental rehearsal that make use of performance simulation in order for musicians to experience and experiment with their 'optimal zone of functioning' (Hanin, 2003).

This study is not without limitations. Firstly, only women that were enrolled in an optional performance psychology module took part. This means that no information of the experience of simulation training for men was gathered and that students may have been motivated to test different solutions that might help improving their performance, which, in turn, may have increased the risk of a sampling-bias. Still, the study is the first detailed analysis of simulation experience in the musical domain, and in this respect, no predicted differences in the quality of experience between men and women can be gleaned from the extant literature. Furthermore, students were encouraged to critically evaluate both advantages and disadvantages of their experience using simulation training. This was hoped to not only prevent sampling-bias but also to reduce the influence of the order of interview and reflective commentaries, respectively.

Secondly, the feedback provided by the virtual displays was of a neutral nature. This was to avoid a first experience of simulation that was overshadowed by particularly positive or negative responses from the virtual audience and audition panel. Subsequent studies should employ the full range of interactive potential of these simulations: for instance, distracting coughing, sneezing, phone ringing in the audience, and different degrees and intensities of feedback as shown through applause, facial expressions and gestures of different valence.

Nonetheless, given the multifaceted nature and impact of performance experiences on musicians and the personal significance it holds even for highly experienced performers, simulation training can be seen as the first of many steps in identifying, training and improving performance-related skills.

7 | Changes in heart rate variability before and during simulation training

7.1 Introduction

Performing in public should be enjoyable and create a sense of accomplishment (Clark et al., 2014). The performer should furthermore be performer high in self-efficacy, leading to an increased control over the performance situation.[1] Both self-efficacy and the perception of an increased control over the performance situation are reinforced through positive learning and feedback experience, allowing the person in charge to respond to performance stress in a physical and mental flexible manner.

A close examination between the link between cardiovascular and pulmonary stress responses and stimuli of different valence has been shown in studies exposing participants to material such as affective film sequences, pictures (Ritz, Thöns, Fahrenkrug, & Dahme, 2005), or music. Pu, Schmeichel, and Demaree (2010), for instance, asked 136 participants

[1]The term self-efficacy was first defined by (Bandura, 1993) in the early nineties, who states that '. . . people make causal contribution to their own functioning through mechanisms of personal agency. Among the mechanisms of personal agency, none is more central or pervasive than people's beliefs about their capabilities to exercise [. . .] to have control over their own level of functioning and over events that affect their lives' (p. 118). As such, a growth in self-efficacy enables an increased ability cognitive, affective, and motivational and selection processes, allowing for a gain in the likelihood (and the belief) to achieve a specific goal. Indeed, the experience of performance stress is greatly linked with self-efficacy and the ability to cope with a distressing situation. Self-efficacy is defined as a multifaceted set of believes in the capability to achieve a goal successfully (Bandura & Locke, 2003) and is substantial when coping with daily hassles; it is about the effort of solving a problem or facing negative experiences and includes cognitive, affective, and motivational processes. These processes are, moreover, affected by: (1) past experiences; (2) the comparison between oneself and an ideal self; (3) coping behaviour; or (4) the feedback—all of them shaping one's efforts for short or long-term achievements.

to watch a negative and a neutral film sequence, while resting respiration was monitored 2 minutes before each stimulus. Additionally, they carried out a verbal and spatial memory task after. Results showed a direct link between the resting respiration, the negative stimuli and a temporarily decreased inhibition of participants' spatial working memory, whilst no such patterns were observed for the neutral stimulus. Frazier, Strauss, and Steinhauer (2004) exposed 56 participants to nine film clips (3 neutral, 3 positive and 3 negative) while measuring participants respiration pattern and heart rate variability. Results revealed a decreased respiration and heart rate variability during both positive and negative stimuli, suggesting that both emotions trigger a similar physiological arousal that can not necessarily be separated by the valence. In contrast, Demaree, Robinson, Everhart, and Schmeichel (2004) randomly assigned 111 to watch either a positive or negative film sequences and monitored participants' respiration and changes in facial expressivity. The results revealed a greater facial expressivity and a lower resting respiration when the negative film stimulus presented. In terms of the frequency distribution of the R-R fluctuations, the majority of studies showed an increased LF power and LF/HF ratio for anxiety, while positive emotions, such as contentment or visual anticipatory pleasure led to an increased T_I and T_E and observable in a slower breathing. By contrast, negative emotions, such as anger or fear resulted in an increased breathing frequency and an increased T_I/T_{TOT} (for a detailed review, see Chapter 2).

In the musical domain, changes in heart rate variability and breathing due to positive versus negative feedback is sparse. Müller and Lindenberger (2011) monitored eleven singers' ECG and respiration during a performance and a baseline measurement. The performance revealed a greater synchronisation of spectral power density between heart rate variability and respiration compared to a baseline measurement, yet no indication of their emotional state was provided. Studer et al. (2012) assessed features of the respiration (T_I, T_E, T_{TOT}, T_I/T_{TOT}) and heart rate variability prior to a private and a public concert. Results showed an increase in heart rate variability, T_E, T_{TOT} and T_I/T_{TOT} during the high-stress condition, which has also been shown to increase their degree of anxiety. Lastly, De Manzano, Theorell, Harmat, and Ullen (2010) examined the degree of musicians' flow and physiological reactions, revealing a positive correlation between flow and increased respiratory depth, yet a reduction in respiration and a decreased heart rate period. Overall, although these studies confirm altered physiological and emotional responses due to a changed performance context, they: (1) do not consider psychophysiological assessments due evaluative performance contexts of opposite emotional valence under a (2) controlled performance setting. To adequately assess individual differences in physiological response style, it is of benefit to provide a constant exposure of either positive or negative stimuli.

The overarching aim of this study is therefore to evaluate the impact of *simulation-based performance feedback* on cardiovascular signatures of stress responses and self-reported anxiety (for more on simulation training and cardiovascular stress responses, see Chapters 2 & 5). To this end, I conducted a close examination of the relationship between stress and structural complexity of heart rate variability in response to two conditions to which the musicians were exposed: in front of three simulated 'judges' providing (1) positive facial and behavioural feedback, and (2) negative facial and behavioural feedback. This was achieved by a conjoint psychological and physiological examination of stress responses within the domain of complexity science (for more details, see Chapter 2).

7.1.1 Method

Participants

Twelve violin students from the Royal College of Music (3 men, 9 women; mean age=21.54 years; *SD*=2.20) were recruited by email. On average, they first performed at the age of 7.18 years (*SD*=1.82), practised 3.04 hours per day (*SD*=1.88), and performed in public 1.54 (*SD*=1.75) times over the month preceding the study.

Participants were informed that they would be required to give multiple, polished performances of the 'Allemande' from J. S. Bach's Partita No. 2 in D minor for solo violin (BWV 1004). This study was granted ethical approval by the Conservatoires UK Research Ethics Committee and was conducted according to ethical guidelines of the British Psychological

Society. Informed consent was obtained from all participants and no payment was given in exchange for participation.

Measures

The State-Trait Anxiety Inventory, state form (STAI-Y1) Prior to and after each performance, participants completed Form Y1 (state anxiety) of the State-Trait Anxiety Inventory (STAI: Spielberger et al., 1983), a 20-item questionnaire measuring the emotional state of the person at the time of completion based on subjective feelings of nervousness and perceived activation and arousal (for more details, see Chapters 2 & 3).

Electrocardiographic ECG was recorded using a wireless commercial device, the Zephyr Bioharness (for more details, see Chapter 2).

Procedure

Each participant attended a 30-minute rehearsal session during which they completed the background questionnaires, got familiarised with the BioHarness and introduced to the concept of the simulation. On explicit questioning, all participants confirmed that they were not currently taking anxiolytic medication or other substances that may affect their perceptions of or alter any physiological responses to performing. The performance in the simulation was scheduled according to the students' availability.

Design For the performance in front of the positively and negatively behaving virtual audition panel, students were asked to arrive 10 minutes before the scheduled performance in order to get fitted with the device and to engage with their pre-performance practice habits (e.g., stretching, warm up, practising, etc.). Stage calls were given by a member of the research team—acting as the backstage manager—5 minutes before their performance in front of a virtual audition panel. When the performer entered the stage, a neutral 'Hello, please start whenever you are ready'-introduction was provided followed by an either positive or negative behaviour, such as making notes, leaning back while simultaneously portraying positive or negative facial expressions and behavioural feedback, respectively. After the performance, the audition panel gave either an enthusiastic and encouraging 'Thank you, this was excellent' or a brief and disappointed 'Thank you for coming'. heart rate variability was monitored throughout, including a 5-minute pre-performance period. The STAI-Y1 was completed prior to and immediately after each performance. The performances were counterbalanced and audio and video recorded.

Data treatment Data treatment and analysis was undertaken using MATLAB (R2013a) and SPSS v21. For the ECG, R-R intervals were detected using cublc spline interpolation and median filter with samples at regular time intervals of 0.25s (for more information, see Chapter 4). All features fulfilled normal distribution and were assessed using a repeated measures ANOVA with Greenhouse Geisser Correction, investigating the effect produced by time (pre-performance, performance, after performance) and feedback condition (positive versus negative), as well as their interaction (for more details on the statistics, see Chapter 3).

7.1.2 Results

State anxiety There were no effects of time or feedback condition, nor a significant interaction between them. On average, students' state anxiety decreased from 34.75 (SD=11.58) before to 28.75 (SD=7.07) after the positive feedback, and from 30.75 (SD=8.04) to 29.42 (SD=7.59) after the negative feedback. Although not significant, a greater degree of anxiety reduction was observed for the time after the positive (mean difference=6.00, SD=4.51) compared to the negative feedback (mean difference=1.03, SD=0.45).

Heart rate variability LF power, which is generally associated with SNS activity and the baroreceptor reflex, showed a significant effect of time ($F_{1,11}$=38.356; p<.001; ηp^2=.77), but no effect of condition or interaction between time and condition. Figure 7.1*a* shows LF before and during the positive and negative feedback condition. The LF increased from pre-performance to the performance period in both the positive and negative feedback condition. The greatest LF activity was detected during the performance in the negative feedback condition.

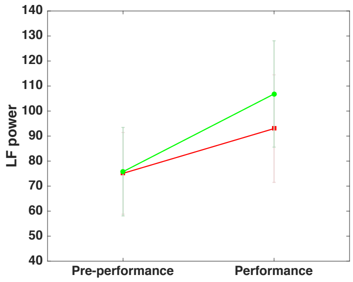
HF power, generally associated with PNS activity and the respiratory sinus arrhythmia, showed a significant effect of time ($F_{1,11}$=40.152; p<.001; ηp^2=.78), but no effect of condition or interaction between time and condition. As shown in Figure 7.1*b*, the HF increased from pre-performance to the performance period in both the positive and negative feedback condition.

The LF/HF ratio, which is an indication of the sympatho-vagal balance with higher ratios suggesting higher overall stress levels, showed a significant effect of time ($F_{1,11}$=10.793; p<.001; ηp^2=.49), but no effect of condition or interaction between time and condition. Figure 7.1*c* shows an increase in LF/HF ratio in the pre-performance period for both the positive and negative feedback condition. The lowest LF/HF ratio was observed during the performance in the positive feedback condition, suggesting a lower sympatho-vagal tone—and, thus, more relaxed physical state—during the performance in front of the positively behaving audition panel (Table 7.1).

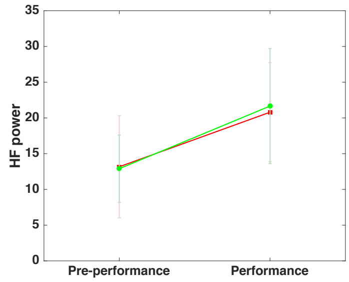
Table 7.1: Descriptive statistics for the (SE) LF, (SE) HF, and LF/HF ratio as well as SE of the full frequency band (0.04 −0.4 Hz) before and during the performance in the positive versus negative feedback condition.

Feature	*Positive feedback Before Mean(SD)*	*Positive feedback During Mean (SD)*	*Negative feedback Before Mean (SD)*	*Negative feedback During Mean (SD)*
LF power	75.10 (16.32)	92.99 (21.49)	75.77 (17.67)	106.83 (21.25)
HF power	13.17 (7.14)	20.80 (6.93)	12.90 (6.18)	21.66 (8.09)
LF/HF ratio	6.94 (3.26)	4.93 (1.90)	6.21 (2.16)	5.56 (1.51)
SE 2 LF+HF	0.63 (0.08)	0.71 (0.05)	0.64 (0.04)	0.71 (0.03)

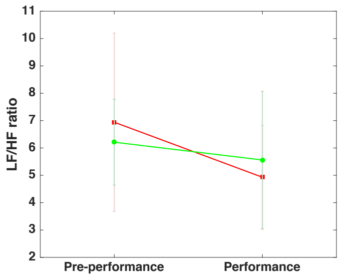
The sample entropy scale factor 2 for the full frequency spectrum (0.04 −0.4 Hz) demonstrated a significant effect of time ($F_{1,11}$=24.961; p<.001; ηp^2=.69), a non-significant effect of condition ($F_{1,11}$= .036; p=.85; ηp^2=.003), and non-significant interaction between time and



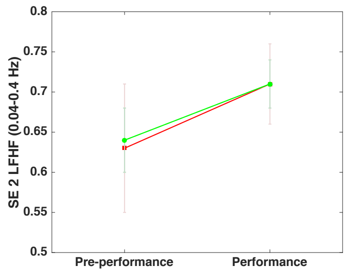
(a) The power in the low frequency band of the R-R time series.



(b) The power in the high frequency band of the R-R time series.



(c) The LF/HF ratio of the pre-processed (filtered, normalised) R-R time series, $0.04 - 0.4$ Hz.



(d) The sample entropy (SE) for the second scale factor of the normalised time series, bandpass filtered within the range $0.04 - 0.4$ Hz.

Figure 7.1: Features extracted from the ECG. The green light represents the positive feedback and the red line the negative feedback response.

condition ($F_{1,11}$=.330; p=.57; ηp^2=.02). Overall, in both the positive and negative feedback conditions complexity for the full frequency spectrum was lowest during the pre-performance period and increased in the performance period (Fig. 7.1*d*).

7.2 Discussion

Auditioning is at the very core of a musical profession, yet little is known about the cardiovascular demands of these performance scenarios. The overarching aim of this study is therefore to establish a relation between the dynamics and timing of physiological stress reactivity in response to a positive and negative performance feedback. In particular, this study explored the impact of simulated training on musicians' heart rate variability and state anxiety. Twelve musicians performed twice in a simulation consisting of an interactive virtual element supported by real environmental cues: once in front of three 'judges' providing positive facial and behavioural feedback and once displaying negative facial and behavioural feedback. The heart rate variability was monitored throughout the performance including a 5-minute pre-performance period while reports anxiety were completed before and after. Four quantitative metrics using power spectral density (PSD) and novel multiscale sample entropy (MSE) techniques were used to estimate stress levels: LF, HF, LF/HF ratio and multiscale sample entropy.

Overall the results show that all metrics indicate a higher physiological stress level in musicians during the pre-performance period compared with during the performance, and that the performance was not affected by the feedback provided. While the LF power (associated with the SNS) increased from pre-performance to the performance period in both performances, the most increased LF activity was detected for the negative feedback condition. The HF power, which is associated with the parasympathetic nervous system and believed to represent a physically relaxed state, also increased from the pre-performance period to the performance period in both conditions, yet did not show any distinctive differences between positive and negative feedback. The LF/HF ratio decreased from the pre-performance to the performances in both negative and positive condition and was lowest during the performance in the positive feedback condition. The MSE result showed lowest complexity during the pre-performance period; in other words, the low structural indicate stress as an inhibition (fewer degrees of freedom), whose excessive levels may harm the performance and/or performers (Williamon et al., 2014).

Limitations This study did not assess other psychological features—apart from state anxiety—that may have been mediated for the changes in the cardiovascular stress features. Future studies may therefore assess state anxiety in a larger sample and alongside other measures, such as self-efficacy, performance confidence or the ability to cope with stress. Performance confidence is strongly linked with past experiences and performance outcomes (Bong & Skaalvik, 2003) and is defined by the ability to monitor, reflect and understand the relationship between performance feedback and musicians' attitude towards performance.

Through the usage of simulation training to increase performance confidence, Tuggy (1998), for instance, demonstrated simulated training to significantly improve medical students' perceived confidence and abilities to perform a sigmoidoscopy when compared with a control group, and a strong agreement in gained confidence for live patient examination. Other studies, such as Jude, Gilbert, and Magrane (2006) showed that over 85% of the students reported higher levels of confidence in their abilities of performing such medical procedures after completing simulation training. More recently, Clayton et al. (2013) explored the feasibility and effect simulated training on doctors' confidence, communication skills, attitudes towards psychosocial care and burnout. The intervention involved three one-hour teaching sessions over three weeks, including written and audio-visual take-home learning material. The results showed significantly higher self-reported communication skills, confidence in delivering relevant topics, a greater attitude towards psychosocial care and an increased sense of personal accomplishment.

Thus far, in the musical domain, simulated training has mainly been applied to reduce physical and mental performance stress. However, at best, simulation training should be integrated into the curriculum and assisted by appropriate feedback in order to ensure an effective outcome. Indeed, the type of feedback is one of the most important features toward effective learning. Studies may therefore examine the application of simulation training as a reward system in order to build up performance confidence and to decrease dysfunctional anxiety and avoidance behaviour (Lyon, 2012).

Performance stress is a (psychological and physiological) multi-level process and closely tied to the performance situation (Kellmann, 2002). A commonly employed paradigm to assess the link between these two is the division of stress responses into stress reactivity and recovery. While stress reactivity is the time of the heart rate baseline to the peak, recovery is the time needed to return back to baseline. Unfortunately, in this study, I only investigated heart rate reactivity and not recovery. Heart rate recovery is an important feature of stress and has been evaluated in well-established 'stress-assessments', such as the Trier Social Stress Test (TSST: Frisch, Hausser, & Mojzisch, 2015; Kirschbaum, Pirke, & Hellhammer, 1993). The TSST is a 15-minute social evaluate performance scenario, in which participants are asked to prepare a convincing speech to get their dream job (5 minutes), to give a presentation in front of an interview panel as to why they are the right candidate for this position (5 minutes), and to solve a mental arithmetic task by subtracting an odd two-digit number from a four-digit number (5 minutes). The TSST has provided stupendous evidence of its reliability, in particular for the evaluation of the hypothalamic-pituitary-adrenal (HPA) stress axis, responsible for the neuroendocrine system and regulating body processes, such as the immune system and energy storage. Other studies used the TSST to assess changes in the balance of the autonomic nervous system, and observed a significant increase in heart rate, and a higher self-reported stress and anxiety (Hellhammer & Schubert, 2012).

The TSST has also been used as flexible and adaptable tool for specific research foci, and therefore paving the way for a huge variety in research applications (Frisch et al., 2015). For instance, the TSST has also been validated as part of simulation training, showing that the TSST was able to significantly increase cortisol levels, heart rate and state anxiety compared to participants' baseline measures (relaxed sitting: Montero-Lopez et al., 2016). The simulation in this study offers a similar concept and allows a performer to experience a pre-performance, a performance and a post-performance period. Future studies should therefore consider the aspect of the stress recovery and evaluate its extent in music performance simulation.

8 Conclusion

8.1 Summary of findings

Stress is an unavoidable part of musical performance, yet its equivocal nature means that it can be seen both as an important facilitator and inhibitor to performance quality. Analysis of stress in music performance also generalises to other aspects of life, yet despite the importance of stress research, studies on objective stress assessment in rigorous controlled performance settings are few and far between. To fill this void, this thesis set out to provide a thorough picture of the physical stress experienced in different performance contexts by applying different methodological approaches to understand and interpret performance stress. In addition, this thesis evaluated alternative methods—simulation training—to help musicians achieve greater performance experiences, but also to bridge the gap between low-stress and high-stress performances.

In studies 1 and 2 (Chapters 3 & 4), I examined the physiological responses to low- and high-stress performance situations before and during the performance from the perspective of a case study and a group of music students. The results showed that, while standard and state-of-the-art methods (discussed in Chapter 2) to analyse physiological data are complementary, multiscale sample entropy provides greater insight into the degree of physiological change experienced by musicians when performing under stress in public, and the evolution of stress levels is also consistent with the difficulty of the music being played. For the frequency domain analysis, in both studies, between performance conditions the HF power was as expected higher for the low-stress condition, suggesting an increased PNS activity and more physical relaxed state. Conversely, the LF power, which is believed to reflect the SNS activity and to be elevated during stress, increased in the high-stress and decreased in the low-stress condition. While this result does not confirm the commonly believed relationship between the LF power and the SNS in response to stress, is in agreement with more recent studies that postulate that the LF power does not accurately reflect the SNS activity (Billman, 2011). Moreover, the results provide conclusive evidence that higher stress levels in musicians are elicited in the pre-performance period compared with the time during the performance, in particular for the high-stress condition. These findings also corresponded with higher levels of self-reported state anxiety by the musicians.

In studies 3 to 5 (Chapters 5, 6 & 7), I introduced a new approach to managing performance stress and enhance performance preparation. For this, I co-developed a simulated performance space based at the Centre for Performance Science, Royal College of Music. The simulated performance space is a training tool that combines a virtual reality display with key features of a real environment (i.e., 'distributed simulation'). The aim of this research was to design and test the efficacy of simulated performance environments in which conditions of 'real' performance could be recreated. Students were recruited to perform in the simulation, to complete questionnaires on their experiences of using the simulation, to provide written reflective commentaries on their experience using the simulation and to attend to a focus group interview to share their personal thoughts and perceptions on how simulation training for musicians could be developed further. In addition, I evaluated the simulation's face validity by monitoring musicians' heart rate variability and state anxiety and by comparing these against musicians' physiological and psychological experiences in a real-life performance scenario.

Overall, the results show that simulations offer a realistic performance experience and that the training is perceived as particularly useful for developing and strengthening performance skills. Furthermore, I found comparable levels of reported state anxiety and patterns of heart rate variability in both simulated and real performance situations, suggesting that responses to the simulated audition closely approximated those of the real audition. Simulation training caused an increased level of physical arousal during the pre-performance period, while responses during the performance were unaffected by the valence of the 'virtual' feedback musicians' received after the performance. A thematic analysis of the qualitative data highlighted the musicians' experiences in terms of (1) their anticipation of using the simulations, (2) the process of performing in the simulations, (3) the usefulness of simulation as a tool for developing performance skills and (4) ways of improving simulation training. The results show that, while simulation was new to the musicians and individual levels of immersion differed, they saw benefits in the approach for developing, experimenting with and enhancing their performance skills. Specifically, the musicians emphasised the importance of framing the simulation experience with plausible procedures leading to and following on from the performance, and they recognised the potential for combining simulation with complementary training techniques.

8.2 Contribution of findings in relation to the literature review

Studies 1 and 2 were done in consideration that (1) wearable sensing technologies have only just generated commercial products suitable for the monitoring of musicians during performance (unobtrusive, ergonomic, discreet) but this convenience is typically compromised by lower signal quality; (2) movement of musicians during performance (often abrupt) introduces a number of electromagnetic and muscular artifacts in ECG which need to be dealt with using techniques that are beyond standard digital filters; (3) an optimal R-peak detection within ECG in such conditions requires person-specific thresholds in data analysis, together with advanced signal processing algorithms for the detection of R-peaks and removal of artifacts; and (4) stress is a complex multi-layered phenomenon and its in-depth analysis may require non-standard methods, since the currently used spectral analyses of the heart rate variability have been shown to be inconsistent.

The well-documented lack of suitable data acquisition devices (robust to musicians' movement and motion artifacts, unobtrusive, discreet, comfortable) and shortage signal processing algorithms for real-world wearable application have so far been prohibitive to larger-scale studies of stress experience in human performance. In this thesis, new wearable physiological recording devices were employed, and I have addressed the imperfections and artifacts in such real-world data through advanced data analysis methods. I focused on combining physiological and psychological measures, analysed within the framework of complexity loss theory, which allowed me to analyse data from a number of performers (Chapter 4) and to extend the current single-person analysis (Chapter 3) to address a more general issue of musicians' emotional and physiological adaptability in musicians to psychosocial stressors.

In relation to previous research in this field, this thesis is—to my knowledge—the first that addresses music performance stress alongside advanced methods in signal processing and drawn from complexity science. In terms of a gross evaluation of musicians' physiological responses to performance stress by means of investigating changes in heart rate (rather than heart rate variability), studies have shown that musicians experience increased heart rate either before or during performance or both in front of an audience and audition panel, respectively (Abel & Larkin, 1990; Brotons, 1994; Craske & Craig, 1984; Yoshie, Shigemasu, et al., 2009). They have examined different pre-performance periods, ranging anywhere from 100 s to 5 min beforehand, and have monitored heart rate at different intervals (which impacts on the capacity to detect subtle changes). In terms of the frequency domain analysis, there are two existing studies that have investigated the ECG frequency distribution in musicians in musicians undergoing different performance contexts (Harmat & Theorell, 2009; Harmat et al., 2010). Their results show an increase in HF at the beginning of the performance, followed by a dominant LF power during the performance.

However, these findings are not comparable to the results of my findings due to the following reasons: According to the recommendations of the Task Force of the European Society of Cardiology, recordings of heart rate variability should be standardised to a minimum of 5-minute epochs to ensure consistent assessment across studies, and analysed by the division of the electrocardiographic (ECG) signal into clinically relevant frequency components (for more details, see Chapter 3). The studies (Harmat & Theorell, 2009; Harmat et al., 2010) that did acknowledge the application of the frequency domain analysis to analyse changes in musicians' heart rate variability used (1) 1-minute intervals to calculate specific frequency components and (2) applied their measures on a sample of flautists and singers. Both the time segments chosen and the sample characteristics (singers and flautists execute distinctive breathing patterns which affect the ECG in a unique manner [for more details, see Chapter 1]) make a comparison with my findings almost impossible.

Thus, the approach used in my thesis allowed a standardised assessment of performance stress supported by validated guidelines provided by the Task Force (for more details, see Chapter 2) on how to analyse cardiovascular signals. The results show that indeed the minutes before a performer goes on stage creates the highest state physical alertness. These findings somewhat resemble the appraisal models such as the component process model (Scherer, 2009, introduced in Chapter 1), which states that an increased SNS activity is most likely found in situation where the person is not in control or has little power to make significant changes. Indeed, based on my personal experience, musicians often do not know what to expect before actually going on stage and perform. This is likely to create a feeling of a decreased degree of capability over the performance situation.

In light of the physiological framework introduced by Berntson et al. (1991), which views responses of the autonomic nervous system as product of the interplay between SNS and PNS that might occur reciprocal (negative correlated) nonreciprocal (positively correlated) or uncoupled (not correlated), including a specific dynamic, range, and lability between them, the results of my thesis suggest that an increase in both LF and HF power during the performance was caused by a positively correlated interplay between between both the SNS and PNS. Conversely, the pre-performance period, which generated a low LF and HF power in the low-stress condition, but a high LF power and low HF power in the high-stress condition suggest that the pre-performance period in the low-stress condition, characterised by a negative correlated SNS and PNS activity, and the pre-performance period in the high-stress condition, defined by an uncoupled or not correlated SNS and PNS activity, do indeed cause distinctive physiological (and psychological) patterns in the autonomic space.

The second part of this thesis examined selected training strategies and their impact, including the application of simulated performance spaces (Chapters 5, 6 & 7). Effective simulations should provide adequate sensory feedback and graphical (virtual) reality which should both be displayed precisely and with low time latency (Mazuryk & Gervautz, 1996). The simulation training in this study was able to present realistic visual and auditory feedback to an extent that allowed the majority of students to experience some feeling of immersion. Immersion experiences in this study were enhanced by auditory and visual cues (background noise and spotlights), and the interaction with the virtual audience and audition panel as well as a combination of high-resolution human computer interface and prompt and fluent feedback, synchronised within and between different modalities (e.g., visual and auditory feedback).

The musicians' preference to use simulation training to enhance specific performance skills, rather than to reduce performance anxiety, is a new finding not previously observed in other studies using simulation training for musicians (Bissonnette et al., 2015; Orman, 2003, 2004). Orman (2003) and Bissonnette et al. (2015) found no discernible and consistent patterns of change in either self-reported anxiety levels or heart rate for musicians taking part in a virtual intervention offering graded exposure to stressful performance situations. My studies focused on the face validity of simulation training rather than the assessment of the simulation as an interventional tool. Indeed, my results suggest that while simulation training may indeed be able to reduce performance anxiety, the results of this study expand the potential of simulation training as a tool to acquire and practice specific performance skills, providing more options for optimising preparation for (high-pressure) performances of all types.

8.3 Limitations

In the following, I would like to emphasise the limitations of my studies before offering future avenues for further work.

In study 1, my case study, while I offer valuable insight into how MSE analysis can be applied to data collected in real-world contexts, the MSE method should be extended to investigate jointly the dynamics of other physiological or psychological parameters (e.g., respiration rate or feelings of anxiety) under stressful conditions.

In study 2, I focused on combining physiological and psychological measures, analysed within the framework of complexity loss theory, which has allowed us to analyse data from a number of performers and to extend the current single-person analysis to address a more general issue of musicians' emotional and physiological adaptability to psychosocial stressors. Further work should embed multivariate physiological data (heart rate variability, respiration rate, skin conductance, etc.) collection and analysis and the examination of these in relation to strategies for coping and self-efficacy, benchmarked against musicians' overall performance quality during different performance events and in different performance contexts.

In study 3, I focused on responses to simulated recital and audition scenarios with relatively neutral and 'well-behaved' virtual observers. Subsequent studies should examine the influence of disruptions and distractions (e.g., coughing, sneezing, phone ringing), as well as more positive and negative observer responses. They should also consider larger samples of musicians, who can specifically be studied in low and high anxiety groups. In addition, there is scope for building and testing further simulated environments: from changing audience size or modifying the number and type of environmental features to involving more performers or altering the performance task itself. It would also be instructive to test whether the degree of background knowledge about the development of the simulations or prior knowledge of whether the performer will encounter a real or virtual audience before they enter the stage (i.e., a blind experiment) would impact how musicians perceive and interact with each simulation.

In study 4, I qualitatively assessed musicians' experience of using simulation training to gather performance experience. However, only women who were enrolled in an optional performance psychology module took part. This means that no information of the experience of simulation training for men was gathered, and through their enrolment on the module, students may not have pursued different solutions to help improve their performances, which in turn may have increased the risk of a sampling-bias. Nevertheless, I encouraged students to evaluate critically both advantages and disadvantages of their experience using simulation training. This was hoped to not only counteract sampling-bias but also to reduce the influence of the order of interview and reflective commentaries.

In study 5, I assessed musicians' feelings of anxiety and changes in their electrocardiographic data whilst performing in front of an either positively or negatively behaving virtual audition panel. Future studies however should consider additional information, such as changes in musicians' self-efficacy or coping abilities. Self-efficacy is the actual belief to achieve a goal successfully while the coping ability is characterised by the efforts—behavioural and psychological—to master, tolerate, or minimise distressing events (Bandura & Locke, 2003). Both could have been affected by the valence of the feedback given and should therefore be targeted in future research. Furthermore, it would have been instructive to assess the musicians' stress signatures in their heart rate 'recovery.' Heart rate recovery is the time needed to return to baseline and has been related to higher levels of trait anxiety and decreased emotional regulation (Pu et al., 2010).[1] Moreover, possible confounding factors, such as health status, sleep patterns, the frequency and intensity of physical exercise, or individual coping strategies have not been addressed in this study. It is widely known that physical fitness, pro-healthy behaviour and active problem-focused coping strategies mediate the performance experience and impact on the level of perceived stress (Daniels & Guppy, 1994). The consideration of these factors may provide a better insight into the physiological stress responses and its distinctive features due to the performance context and individual response specificity (Scherer, 2009).

[1]Future research should therefore clarify the relationship between emotional and physiological reactivity/recovery with regards to individual characteristics, such as appraisal and coping (Stephens, Christie, & Friedman, 2010).

8.3.1 What I would have done differently and why

My research focus in this thesis was the assessment and evaluation of performance stress and simulation training amongst musicians. While the studies conducted provide an initial insight into which methods can be used to analyse stress and simulation training, I did not consider the evaluation of the concept of performance stress, which not only involves two specific stress responses (heart rate variability and the feeling of anxiety), but also the consideration of musicians' health-promoting behaviours and coping abilities (for more details, see Chapter 2). As described in Chapter 1, performance stress is determined by a specific stressor and its interpretation and processing, followed by a stress response through the activation of specific areas in the central nervous system. The stressor of performing is furthermore interpreted and processed automatically, or it may incorporate higher cognitive processes, Including a detailed evaluation in terms of motivational relevance and congruence, future expectancy and whether the situation is self- or other-imposed (Compas et al., 2014; Scherer, 2009). Based on my set-up of the study designs, it was not possible to determine to what extent musicians experienced performance as a stressor and to what extent they applied coping strategies (and, more importantly, which ones) to deal with performance. This would have added a more in-depth understanding of performance stress because it allows for consideration of the stressor, the interpretation and the stress response.

In terms of the simulation training, I would have considered a more theoretical approach in understanding the impact of simulation training on learning. While the feedback form based on Kassab et al. (2011) enabled an assessment of how realistically the simulation was perceived and whether the simulation can be used to tackle specific performance skills, it either only partially addressed or did not address the well-established stages of learning proposed by Kirkpatrick and Kirkpatrick (2006), which involve four levels of evaluation: whether the participant liked the simulation (i.e., reactions), learned from the simulation (i.e., learning), applied what they have learned from the simulation training (i.e., behaviour), and whether there is an increased feeling of safety regarding real-life performance following the implementation of the simulation training (i.e., organisational impact). Acknowledging these aspects would have helped to gain a better understanding of the impact of simulation training—not only regarding performance stress responses, but also in terms of the actual benefits of simulation training as a learning environment.

8.4 Avenues for future research

The findings of this thesis offer avenues for further research in two main areas, namely in terms of (1) methodological considerations and (2) practical considerations. Thus, the following sections focus on performance stress and endocrinological responses, performance stress and pulmonary responses, performance stress and neurological responses, performance stress and behavioural responses, performance stress across age and musical genres, as well as simulation training and other virtual displays and simulation training and other sensory feedback. From a practical point of view, future studies are encouraged to address the topics performance stress and Alexander Technique, performance stress and physical exercise, performance stress and mental skills training, performance stress and self-regulated learning, performance stress and smartphone applications performance stress and the optimal zone of functioning.

8.4.1 Methodological considerations

Performance stress and endocrinological responses

Physiological and psychological stress responses not only result in alterations in cardio- or pulmonary functioning, but also in activation of the endocrinological system. The endocrinological system is the link between the central nervous system and the endocrine system and responsible for distributing hormones into the body. As such, the evaluation of the endocrinological responses, in particular the release of the commonly known stress hormone cortisol appears a likely next step for further research.

To put this into context, two important mediators between performance stress and the release of stress hormones are the hypothalamic-pituitary-adrenal axis, encompassing the hypothalamus, the pituitary and the adrenal glands (located in the kidneys), as well as the sympathetic adrenal medullar system, which is mediated by the sympathetic nervous system and the adrenal modular (also a part of the adrenal glands). The hypothalamic-pituitary-adrenal axis is an auto-regulated system that prevents the human system against homeostatic disturbances (Nicolson, 2007). It functions as a stress control system and, in doing so, ensures a balanced distribution between an external/internal stressor and the physiological response. This is done by the activation of the central nervous system and the hippocampus, sending corticotrophin-releasing hormones and arginine vasopressin (AVP) from the hypothalamus to the anterior pituitary gland. The anterior pituitary gland then secretes the adrenocorticotropic hormone, which is circulated into the blood system. Reaching the zona fasciculata (i.e., middle zone) of the adrenal glands, located in the kidneys, it promotes its two divisions, the outer adrenal cortex and the inner medulla—one producing glucocorticoids, such as cortisol, the other, related to the sympathetic adrenal medullar system, providing catecholamines, such as epinephrine or norepinephrine. The function of the hypothalamic-pituitary-adrenal axis can be seen as a '…closed-loop system involving tight negative-feedback control mediated by the glucocorticoids exerting multiple regulatory actions' (Fulford & Harbuz, 2003, p. 47). The regulated feedback can be of short or long duration, causing either an immediate circulation of glucocorticoids, lasting for 5-30 minutes, or a delayed response with increased glucocorticoid levels which lasts for up to four hours.[2]

If the stress becomes chronic, the endocrine system is deregulated, resulting in a deterioration and decrease in general health, characterised through muscle loss, immune system suppression, depression and increased blood pressure and cholesterol and body fat. Unfortunately, in the musical domain, only a handful of studies have addressed th impact of performance stress on endocrinological responses.

Starting chronologically, Fredrikson and Gunnarsson (1992) assessed endocrinological reactions, including cortisol, epinephrine and norepinephrine to performances by string musicians. Endocrine measures were collected via urine samples one hour before and 30 minutes

[2]In general, the cortisol level throughout the day fluctuates in designated patterns, with the highest/lowest level in the morning/night, including a daily range between 6-23 mcg/dl (micrograms per decilitre) per day (Schmidt-Reinwald et al., 1999), and is influenced by emotional and physical stress (e.g., exercise, depression, anxiety) or by the intake of substances, such as caffeine and nicotine.

after musicians were asked to perform in two conditions: (1) no audience and (2) a public concert. Subjective reports were recorded using the Personal Report of Confidence as a Musician (Appel, 1976) and the Report of Confidence as a Speaker (Paul, 1966). The results demonstrated significantly elevated endocrinological responses prior to the public performance compared to no audience.

Gill, Murphy, and Rockerd (2006) asked 35 19-year-old students playing different instruments to perform a technical performance exam in front of two judges while a baseline measure was taken six weeks after. Questionnaires, such as the modified competitive subjective state anxiety questionnaire (CSAI-M: Martens et al., 1990), the Music Performance Anxiety Questionnaire (Cox & Kenardy, 1993), as well as saliva samples were collected during the baseline measure and after the jury condition. The results revealed a significantly higher cortisol response alongside subjective reports during the exam. However, the relation of performance anxiety intensity and direction was not specifically examined.

Halleland, Sornes, Murison, and Ursin (2009) explored the relationship between subjective health complaints/coping strategies and stress reactivity. Thirty-five musicians of a philharmonic orchestra took part by filling in a Subjective Health Complaint Inventory (Eriksen, Ihlebaek, & Ursin, 1992), a questionnaire that asks about 29 common health complaints, rated on a 4-point Likert Scale (0='Not bothered', 1='A little bothered', 2='Somewhat bothered', 3='Much bothered'), experienced during the last 30 days. The items were separated into five domains: (1) musculoskeletal complaints; (2) 'pseudoneurology' (tiredness, mood changes); (3) gastrointestinal complaints; (4) allergic complaints; and (5) cold. In addition to the Subjective Health Complaint Inventory, the Utrecht Coping List was administered, assessing seven different coping strategies (e.g., active problem-solving, palliative reactions, passive avoidance, seeking social support, depressive reaction patterns, expression of feelings, and comforting thoughts) rated on a 4-point Likert Scale, with higher scores indicating a higher level of active problem solving abilities (e.g., calm in the situation, considers different solutions, and solves the problem in an instrumental way). Cortisol samples were collected two days before a major concert, on the day of the concert, and two days after the concert at the following times: at awaking [T1], 30 minutes after awaking [T2] and at 8pm [T3]. Results for the Subjective Health Complaint Inventory showed no difference between musicians and the remaining population, except for 'pseudoneurological' complaints. Cortisol was significantly more increased during the concert [T3] than during the normal workdays. Musicians scoring high on the Subjective Health Complaint Inventory showed higher cortisol concentrations during evening workdays [T3] than musicians scoring low on the Subjective Health Complaint Inventory. In general the Subjective Health Complaint Inventory explained 15% of the cortisol level, while the sub scale gastrointestinal complaints accounting for 24% cortisol release at awaking [T1]. Last, musicians using an emotion-focused problem solving approach were related to 18% of the cortisol level. No other associations between cortisol and Subjective Health Complaint Inventory or the Utrecht Coping List could be found.

Pilger et al. (2014) collected pro-inflammatory and oxidative responses, such as cortisol, plasma myeloperoxidase, serum CRP, and plasma IL-6 by blood (venepuncture) and saliva samples (Salivette cortisol tubes) of 48 members of a symphony orchestra. Levels of state anxiety were collected by self-reports (Self-assessment Manikin: Bradley & Lang, 1994) on the day of the rehearsal and the performance, while blood samples were taken immediately after and during their break in both low- and high-stress conditions. Saliva samples were collected at five time points: at awaking (T1), after 30 minutes (T2), between 11:30 am-12:30 (T3) pm 3:00 pm-4:00pm (T4) as well as between 6:00 pm-7:00pm (T5). Finally, a Work ability index questionnaire (WAI: Tuomi, Ilmarinen, Jahkola, Katajarinne, & Tulkki, 1998) with scores ranging from 7 to 49, including the categories excellent (44-49 points), good (37-43 points), moderate (28-36 points), poor (7-27 points) was used. Results demonstrated a significant increased level of cortisol for T1, T3, T5, IL-6, and MPO on the day of premier compared to the dressed rehearsal, a significantly increased SAM from low- to high-stress condition. Age was negatively correlated with the WAI. A correlation between physiological and psychological (Self-assessment Manikin) measurements was only found for the myeloperoxidase and cortisol at T3. No association to other biomarkers was found. Interestingly, a comparison between Second violinists and First violinists showed a significant increased level of cortisol in the first violin.

Most recently, Fancourt, Aufegger, and Williamon (2015) examined the impact of singing in a low-stress performance situation and a high-stress live concert on levels of glucocorticoids (cortisol and cortisone) in fifteen professional singers. This study demonstrated that singing was associated with a reduced cortisol/cortisone ratio, indicating a diminished overall stress response. Furthermore, across performances, low-stress conditions showed decreases in cortisol and cortisone, while high-stress conditions triggered an increase in both. These results confirm previous findings that low-stress performance conditions lead to reductions in cortisol and that high-stress conditions lead to increases, which is indicative of a more general hypothalamic-pituitary-adrenal axis response (Beck, Cesario, Yousefi, & Enamoto, 2000).[3]

Based on these results, future studies are encouraged to look at endocrinological responses in a variety of musical settings. Indeed, measuring and evaluating endocrinological responses, such as cortisol, are quite straightforward (Nicolson, 2007). Cortisol can be assessed in blood, saliva, or urine. Depending on the technique, each method offers advantages and disadvantages. Collecting urine, for instance, has the negative side effect of reduced compliance of participants as well as the challenge of safe transportation from testing site to laboratory. On the other hand, it does not really interfere with the participants' routines, providing samples every 2-3 hours and, thus, is preferably used for longitudinal studies. Blood has the advantage of containing a high level of cortisol concentration, but also requires slightly invasive finger pricks and participants need to be warned in advance. Given these practical problems, the majority of research has begun to focus on the analysis of cortisol in saliva. Collecting saliva can be done without a licence and is easy to gather via cotton ropes, swabs or sponges, triggered by chewing or acid in the cotton swab (Kirschbaum & Hellhammer, 2000). They can be stored at room temperature, in a refrigerator, or in a freezer (Nicolson, 2007). Samples kept at room temperature are durable from 7 days to 4 weeks, in a refrigerator up to 3 months and in a freezer up to years, alleviating the risk of decay over time. Moreover, they are not affected by thawing or refreezing (Garde & Hansen, 2005).

[3]It has to be taken into consideration that the hypothalamic-pituitary-adrenal axis response is also modulated by the appraisal of the distressing event, and thus, the degree to which the stress response is seen is impacted by the ability to cope with the stressor (Kemeny, 2003). The evidence of increased glucocorticoids in response to high-stress singing found in their study, independent of experience, age or number of previous concerts, shows that regardless of the constant exposure to performance situations, singers still exhibit a rather basic fight-flight response.

However, to avoid any biases of cortisol concentration, participants should be asked to not drink liquids, eat or smoke at least 2 hours before the assessment.[4]

Last, it is important to mention that there are several ways to extract cortisol, most of them done in specific laboratories. One of the most commonly used techniques are the radioimmunoassay (RIA), the time-resolved immunoassay with fluorometric detection (DELFIA) and the enzyme immunoassay (EIA: Nicolson, 2007), all of which rely on the competitive binding between free cortisol and reagents.[5] Once the data is available for further processing, the researcher may extract the cortisol concentration through the calculation of the percentage, the ratio, and the mean and standard deviation of the temporal shifts in cortisol release levels. Other, more advanced tools that enable a meaningful interpretation of the data is the examination of the area under the curve with respect to the ground and the overall increase, respectively. The main argument of computing the area under the curve is its simple statistical analysis and the increase in statistical power without having to sacrifice information collected over multiple time points. While the area under the curve with respect to the ground detects the changes occurring over time, the area under the curve with respect to the increase identifies the overall intensity (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003). For the latter, the main intention is to get more information about the changes in the cortisol reaction curve.[6] After the extraction takes place at the laboratory of choice, statistical packages such as SPSS can be used to analyse and make sense of the results.

Performing music in public is widely recognised as a potentially stress-inducing activity. However, despite the interest in music performance as an acute psychosocial stressor, there

[4]Recently, secretions of cortisol have also been found in skin and tested hair samples (Sharpley, Kauter, & McFarlane, 2009). This was tested in an exploratory study by Sharpley et al. (2009), who compared cortisol, collected by means of saliva and hair samples before and after an acute physical stressor (pain inducing stressor) was applied on one arm of the participant. Interestingly, cortisol extracted from the hair samples were '... (a) swift but transitory; (b) localised to the site of the pain; and (c) independent of the central hypothalamic-pituitary-adrenal axis as represented by salivary cortisol' (Sharpley et al., 2009, p. 760), supporting the 'localisation' hypothesis—a 'peripherally' working hypothalamic-pituitary-adrenal axis.

[5]The choice of technique depends on the availability of the laboratories, the price of chemical kits, but also on the characteristic of the sample of population; for instance whether the participants that take part in the study are classified as either healthy or clinical participants.

[6]A major limitation of these two, however, is the requirement of a steady and gradual increase of cortisol concentration. If this is not the case, the area under the curve goes towards zero, suggesting a spuriously non-existing increase.

has been relatively little research on the effects of public performance on the endocrine system. The simplicity of collection and analyses of endocrinological responses make the investigation of these responses extremely useful.

Future studies should address these responses in relation to solo versus group performances, as well as between men and women. It has been shown that both differ in their baseline physiology (heart rate, breathing rate, cortisol: Kirschbaum & Hellhammer, 2000). All these unresolved questions offer great potential for some new insights into musicians' overall physiological responses to performance stress.

Performance stress and (cardio-)pulmonary responses

Musical performance typically leads to an activity in both cardio and pulmonary responses, including changes in heart rate variability and breathing. While the impact of performance stress on heart rate has been addressed, corresponding research into the respiratory effects of performance stress by comparison is meagre. This is not surprising given that traditional measures obtaining respiration are either too intrusive or simply to imprecise to offer an adequate evaluation of pulmonary functioning. Moreover, the respiratory responses to stress are complex, and decomposition into meaningful respiration metrics have resulted in a variety of methods of analyses. To put this into context, respiration can be classified in terms of (1) volume and timing parameters, (2) measures that evaluate the analysis of the breathing curve, and (3) measures reflecting gas exchange (Boiten, Frijda, & Wientjes, 1994). While the aspect of volume and time parameters have been discussed in Chapter 1, the measures that evaluate the analysis of the breathing curve apply the so called 'shape factor,' which helps to determine the phase of expiratory pause, which is not considered by the volume and timing parameters. Last, the measures reflecting gas exchange allow for the assessment of the arterial carbon dioxide tension. The arterial carbon dioxide determines the level to which ventilation is in balance with the metabolic output. Irregular or disproportionate ventilation (also called hyperventilation) causes more arterial carbon dioxide than can be disposed by the organism and results in a decrease of partial arterial carbon dioxide lower than the normal range. Researchers interested in analysing the measures reflecting gas exchange should evaluate whether the ventilation is in balance with the metabolic processes and also consider other metrics, such as energy expenditure (Wientjes, 1992).

Devices to record respiration, among others, are the spirometer, measuring the volume of air during inhalation and exhalation, or employ measures to monitor the motions executed of the chest and the abdomen. However, both involve a degree of intrusiveness for the performer, making the application of these devices in performance science less common.

To date, only one study has faced the challenge of respiration detection alongside the analysis of heart rate variability during music performing (and using state-of-the-art signal processing approaches). This was achieved by Hemakom, Goverdovsky, Aufegger, and Mandic (2016), who evaluated the very specific activity of respiration during choir singing, where highly synchronised performance of the individual singer is dictated by the tempo and demands of a musical score. In doing so, their aim was to provide a quantitative measure of the level of cooperation, displayed by the synchronisation between singers' responses in respiration and heart rate variability. To this end, they employed two new measures, the intrinsic phase synchrony and intrinsic coherence in five members of a choir and the conductor during a low-stress rehearsal and a high-stress concert. The results showed that both methods applied reveal a noticeable increase in coordination from the rehearsal to the performance, less agreement has been observed between groups, such as the choir and the conductor. Furthermore, the intrinsic phase synchrony was able to identify phase relationship of both physiological signals in all situations effectively, allowing for a purposeful interpretation of the data. They have also shown that the characteristics of the SNS and PNS shown during both performance conditions were primarily mediated by respiration.

Overall, both the proposed techniques revealed synchronisation of singers' heart rate variability and respiration. Future studies are therefore encouraged to evaluate this promising new avenue of signal processing to different performance contexts, using a bigger sample size or a more controlled performance environment, such can be found in simulation training.

Performance stress and neurological responses

As mentioned above, performance stress has negative effects on the autonomic nervous system and physiological responsiveness. These effects can be identified and quantified in biosignal channels, such as ECG, and electromyography (EMG) and electroencephalography (EEG).

Despite the majority of research that exists to examine the relationship between physiological responses and stress, little has been done to understand the potential impact music performance stress may have on musical performance. So far, research has shown that stress reducing experiences, such as the sensation of positive emotions or approach-related behaviour is mainly reflected in the left hemisphere of the brain, while the right hemisphere represent the feeling of negative emotions and avoidance behaviour. In particular, these effects could be found in the prefrontal activity in the brain, which is mainly responsible for distinctive cognitive and behavioural operations, such as the process of attentional selection and emotional regulation (Lewis, Weekes, & Wang, 2007). The question however remains whether stress or the experience of anxiety is also related to this brain region. Recent research suggest that the experience of anxiety is predominantly represented by activations of brain areas including the dorsolateral, orbitofrontal and ventromedial prefrontal cortices. All three are specific prefrontal cortical subregions: The dorsolateral prefrontal cortex has been shown to be related to action selection and processing task-relevant representations (Mars & Grol, 2007), while the orbitofrontal prefrontal cortex and the ventromedial prefrontal cortex are the centre for emotional regulation and decision making (Bechara, Damasio, & Damasio, 2000). And indeed, while the examination of these regions in relation to a number of distinctive positive and negative mood states or behaviour such as depression or fear have been conducted, less attention has been paid to the general experience of stress. Stress and anxiety share certain features, yet while anxiety is the emotional perception that may lead to stress or be a precursor, stress is a more general concept and involves the activity of interpretation and evaluation as well as the application of coping strategies.

Thus far, there is some evidence that stress and health, but also decreased immune functioning (e.g., increase in cortisol levels: for more details see performance stress and endocrinological system), is reared to an increased activation in the right hemisphere of the brain (Davidson, 2003). In particular, it has been demonstrated that stress leads to a relatively greater right prefrontal activity during the exposure to high-stress scenarios and in comparison to low examinations of stress (Lewis et al., 2007).

A number of studies look at EEG and musical performance, however tend to direct their focus towards the role of neurofeedback for musicians. Gruzelier et al. (2014) addressed utilising alpha/theta and sensorimotor rhythm (SMR) neurofeedback training amongst both novice and advanced instrumentalists during the performance of a prepared and an improvised piece. Their findings identified a distinct correlation between alpha/theta training and the assessed domains of musicality/creativity, as well as communication and technique. Furthermore, Gruzelier and Egner (2004) reported improvement in musical performance amongst children following SMR specifically designed for their study.

These studies provide first insights into biofeedback mechanisms to maximise performance outcomes, yet there is virtually no research looking into the detection of performance stress as a warning mechanism. Even across research, the literature that aims to identify the degree of cognitive neuro-fitness and the prevention of detrimental performance stress is sparse. Haak, Bos, Panic, and Rothkrantz (2009) was one of the first who developed a stress detecting protocol using eye-blink artifacts in the brain activity by means of EEG monitoring. The set up of the design included a car driving simulation where stressful emotions were triggered through steep curves and attention seeking billboards, as well as mental task application. Using low cost EEG solutions, a correlation analysis between eye blink frequency with experienced stress revealed a significantly higher frequency of eye blinks in stressful situations, as well as significantly more active brain activity during the mental task.

As such, developments in the technology sector have allowed engineers such as Emotiv Systems to produce their EPOC devices,[7] which allow for a complex and detailed EEG measurements whilst experiencing only little disruption and interference with the performer. This

[7]http://emotiv.com

also includes the fact that measures can be taken within a musician's familiar surroundings (e.g., on stage), instead of using laboratory-based hardware and research settings. A key principal of monitoring musicians' experience of performance stress should be in acknowledging that utilising such technology enables for complex scientific studies to take place in a natural environment.

While this is an exciting step towards a better understanding of performance stress, more research is needed to develop real-life and meaningful application that can be administered on a potentially daily basis. It is for instance known that repeated stress causes impairments of spatial memory performance (Luine, Villegas, Martinez, & McEwen, 1994), a particular crucial aspect musicians should be prevented of. Studies should identify a correlational relationship between an increase in performance stress and the neural activity measured, based on the change in for instance performance context. Alpha and Beta wavelengths measured by the EEG device should serve as the focal measuring point, being the wavelength indicative of conscious arousal (Gruzelier et al., 2014). If a correlation is clearly identified, future studies would be able to pose the possibility that an intervention based on neural activity representative of performance stress could be designed. Thus, further research is needed to develop such detection systems that help musicians to reduce performance stress and to achieve an optimal amount of cognitive neuro-fitness.

Performance stress and behavioural responses

Behavioural manifestations of performance stress can be observed in broad as well as more specific contexts. While the former is linked with '...the tendency to escape from or avoid the source of one's distress' (Salmon, 1990, p. 59), the latter is illustrated by behaviour displayed just before a performance, such as exaggerated fidgeting or excessive pacing.

The tendency of procrastination and finding excuses not to attend an important audition is defined as 'behavioural self-handicapping' (Ferrari, 1992). So far, researches about behavioural symptoms of performance stress have been few and far between.

Craske and Craig (1984), for instance, explored two features of behavioural components in musical performance stress; the first was carried out by judges rating touch, phrasing, pitch, rhythm, tempo, dynamics, memory and overall effectiveness on a 10-point Likert scale; the second measure was obtained through the use of a timed checklist, including lifted shoulders, stiff back and neck, deadpan face and moistened lips within 20-second intervals. Videos were presented in a counterbalanced order, and judges were neither aware of the group classification (high- versus low-anxiety musicians) nor the performance condition (alone versus audience). The results demonstrated different behaviours in anxious pianists compared to relatively non-anxious pianists when performing in both conditions. However, these differences were not reflected in the performance-quality ratings from low- to high-stress performance conditions.[8] No effect of the features of the musicians' behaviour on the performance-anxiety rating was found.

Wolfe (1989) focussed on behavioural coping strategies and performance stress and, through a survey, found that maladaptive components of performance stress, namely nervousness, apprehension and distractibility, are often an indicator of avoiding coping strategies, hindering the promotion of relaxation and the perception of arousal needed for an optimal performance outcome. Moreover, he discovered that musicians who apply emotion-focussed strategies (for more details, see Chapter 1) are more self-consciousness and experience more disruptive and distracting cognitive activities (e.g., worry and rumination).

More recently, Juchniewicz (2008) investigated the impact of physical movement on the perception of musical performance. He asked 112 students to rate a pianist giving a performance without exhibiting head, facial or full-body movement on a 5-point Likert scale, asking about phrasing, dynamics, rubato and overall musical performance. Interestingly, the results showed a significant increase in the performance-quality rating with increased body movement compared to no movement at all, all of which was independent of the gender of the students (Davidson, 2012; Tsay, 2013).

While these studies offer some insight into behavioural aspects and music-performance

[8]It is worth mentioning that highly anxious musicians had a significantly lower performance-quality rating compared to non-anxious musicians under high-stress conditions.

stress, as well as its impact on musical performance-quality ratings, noticeably more research needs to be done to understand the interactions between performance stress and behaviour, implementing more objective analysis methods for evaluation.

Some rigorous research into measuring behavioural changes to assess performance quality and to understand different patterns in behaviour due to performance context has been done in medicine, particularly for simulation-based training and multidisciplinary team settings. This research has shown that the degree of verbal or non-verbal communication as well as agreement between members is vital for effectiveness at both individual and group-organisational levels.

Thus, in order to set up valid simulation-based training for behavioural observation, Shapiro et al. (2008) offer four main principles or steps that future studies should consider for their own training development. In step 1, the researcher should determine the overall learning outcome, such as (verbal and non-verbal) communication, co-ordination and co-operation between musicians. To obtain a more systematic view of competencies, behavioural measures should identify these in terms of task-work versus teamwork. While task-work can be estimated by the frequency and subjectively assessed importance of the co-ordination during the specific task, teamwork can be targeted by the team's change in knowledge, skills and attitudes.

In step 2, the researcher should provide a guided practise for teamwork behaviour to help ensure specific skill acquisition (e.g., group stage presence, communication with the audience). Practise opportunities should focus on specific skills, with immediate follow-up feedback about what can be improved and how these improvements can be executed. As such, simulation-based scenarios should contain 'triggers' designed to elicit a given teamwork response (e.g., specific response/question from the audition panel or audience).

In step 3, measurements should be developed to provide opportunities for learning. Simulation-based training works most efficiently when measures are developed to identify team performance. This can, for instance, be achieved through observation protocols, targeted teamwork designs and the assessment and monitoring of specific behavioural markers that are applied so that the observer knows exactly what to assess and what behaviours to look for. The feedback should then be applied by means of a structured template that allows for a debriefing of behaviours that did or did not occur.

In step 4, the researcher should establish a robust debriefing protocol that is linked with the feedback and the targeted learning outcomes. The feedback should be able to determine the strengths and weaknesses of a group performance, with the researcher applying a diagnostic scenario-based tool that allows effective debriefings.

For learning opportunities and the open and honest involvement of the trainees (where the performance process can be shared and discussed, and specific objectives can be addressed), simulation training, as a safe environment, offers an ideal platform with a decreased risk of criticism and blame. As such, in order to ensure the establishment of behavioural strategies that benefit team performance, a collection of scenarios should be created, with each scenario focussing on a specific set of knowledge, skills and attitudes.

Performance stress across age and musical genres

Classical musicians have been subject to great interest, providing insights into musicians' personality traits, health-promoting behaviour, and how these two are related to musicians' mental stress responses to different performance contexts. In contrast, there is little evidence of performance stress of musicians from other musical fields, such as rock music, as well as how physiological responses may differ in age such as young musicians or professionals.

Studies that have investigated physiological responses in young versus professional musicians have predominantly focused on changes in heart rate. Inesta et al. (2008), for instance, monitored heart rate during solo performances and during a performance in an orchestra. By calculating the percentages of the Maximum Theoretical Heart Rate (%MTHR) they could demonstrate that musical performance is similar to an exercise carried out on a cycle-ergometer classified as 'moderate' to 'heavy' levels of work intensity.

Other studies carried out include the work by LeBlanc, Chang Jin, Obert, and Siivola (1997).

They asked members of school bands (no age was provided) to perform: (1) in a private condition; (2) in front of another person; and (iii) in front of an audience (peer group and teacher). A self-report on anxiety (10-point Likert Scale and with higher scores indicating a higher degree of anxiety) designed by the authors was administered immediately after the performance, while heart rate was measured at 5-second intervals for the first two minutes of the performance. The results showed significant differences between the self-report and all three conditions, with the third condition producing the highest levels, followed by the second and first condition. While heart rate was nit significantly different in condition one and two—taken together—responses were significantly decreased compared to the performance in front of the audience.

Ryan (1998) asked 12-year-old pianists to undergo a baseline measure and to perform in a recital. The psychological questionnaire administered was the Coopersmith Self-Esteem Inventory (Coopersmith, 1959), while heart rate was monitoring at 5-, 15-, 30-, or 60- intervals, prior to, and during, the recital. The performance was evaluated by two expert pianists in terms of technique, tone, rhythm, musicality, interpretation, balance, dynamics, and tempo (60 'Very poor' to 90 'Distinction'). Results showed significantly less self-esteem during the performance compared to the baseline. This was also mirrored in the heart rates, gradually increasing from baseline to the pre-performance to the performance condition. In contrast, no significant difference was found for the performance evaluation. Furthermore, no correlation was detected between the physiological and the psychological measures.

Ryan (2004) monitored 26 young music students (no age provided) during a 45-minute baseline measure, a piano lesson and a recital condition. While the State and Trait Anxiety Inventory-state form for children (Spielberger & Edwards, 1973) was filled in during the pre-performance period, the heart rate was monitored throughout both conditions in 15-second intervals. An evaluation was carried out in terms of by two expert pianists (r=.84) in terms of technique, tone, rhythm, musicality, interpretation, balance, dynamics, and tempo (ranging from 60 ['Very poor'] to 90 ['Distinction']). Moreover, anxiety indicating behaviour was rated by means of indicating exaggerated feet, legs, body, arms, hands, instrument, head and face movements.

Boucher and Ryan (2010) assessed 66 3-4 year old students during two performances in front of family members on two successive days. Psychological assessment included the State and Trait Anxiety Inventory-state form for children (Spielberger et al., 1983), the Music Performance Anxiety Inventory for Adolescents (Kenny & Osborne, 2006) and self-reports on feeling in terms of performance, musical activity and perceived musical competence. Cortisol measurements were taken three times one week before (baseline) and after the concerts. The performance was also at 15-second intervals, addressing overt-emotional behaviour, movements of feet and legs, arms and hands, body, head/face, interactions with objects and people. Results showed that 75% of the sample experienced signs of anticipatory stress, yet no statistical report was provided. Previous musical performance experience had a significant impact on anticipatory stress with more experienced students showing a greater level of perceived stress. Sex and age did not contribute to the outcome. Cortisol was significantly higher after the first concert, but decreased to an almost baseline level after the second performance. Previous experience significantly impacted on the cortisol level with more experienced musicians showing a greater cortisol secretion. Two independent observers (intra-reliability=.89) detected significantly more overt-emotional behaviour (e.g., avoidance and refusal) in the first concert compared to the second concert and baseline measure. Anxious behaviour was more likely in 3 than in 4-year-old students. No information on each category ('behavioural assessment') was provided. Low-anxious students revealed a higher cortisol release than moderately anxious students. This accounted for both baseline measure and concert conditions. No correlation between all three measurements was detected.

In contrast, other musical genres such as rock musicians have mainly been explored in terms of their life-style. Rock musicians carry out immense physical engagement with an audience and the extent to which they endeavour and support healthy (pre-performance) behaviour has a direct impact on their degree of stress reactivity and, therefore, stress management (Lehmann & Kopiez, 2013). However, most studies on rock musicians have only shown interest in rock musicians' life-style, personality traits (Gillespie & Myors, 2000; Hernandez, Russo, & Schneider, 2009), substance abuse (Miller & Quigley, 2011) and how they are shaped by stereotypical perception (Cameron, Duffy, & Glenwright, 2014).

Gillespie and Myors (2000), for instance, asked 100 rock and pop musicians to complete the Revised NEO Personality Inventory (Costa & McCrae, 1992), concluding that rock musicians—compared to the wider population—tend to be greater in openness, neuroticism and excitement seeking and poor in agreeableness and conscientiousness. Miller and Quigley (2011) examined the relationship between personality traits, musical genre and substance abuse. A sample consisting of 226 amateur and professional musicians were asked to complete a personality questionnaire (Zuckerman, Kuhlman, Joireman, Teta, & Kraft, 1993), a short test of musical preferences (Rentfrow & Gosling, 2003) and a questionnaire on drug abuse (Sobell, Kwan, & Sobell, 1995). Results revealed high levels of correlation between sensation seeking, substance abuse, such as tobacco, alcohol, and marijuana in rebellious genres, such as heavy metal, punk and rock music as opposed to jazz, classical or pop music. Hernandez et al. (Hernandez et al., 2009) examined personality traits and cognitive abilities in four rock band members by administering the Minnesota Multiphasic Personality Inventory 2 (MMPI-2: Hathaway & McKinley, 1940) and the Wechsler Adult Intelligence Scale III (WAIS-III: Wechsler, 1958). The results showed an increased tendency towards depression, anxiety, pessimism, and egocentric attitudes, yet also a high degree of dedication, persistence, and acceptance of third-party helpers.

Most recently, Cameron et al. (2014) reported the extent to which personality traits have been formed by stereotypical and social perception. Five hundred and ten musicians were asked to categorise their band 'position' (e.g., 'What are singers like'?) and to complete a range of personality questionnaires (e.g., Mini-IPIP: Donnellan, Oswald, Baird, & Lucas, 2006). Perceptions and personality traits significantly predicted each other, with e.g., singers exhibiting greater extraversion than bassists, as well as higher openness to experience than drummers.

The studies above offer first insights into personality traits and the life-style of rock musicians, however, none of them investigated rock musicians' physical and mental responses to performing. Future studies may therefore focus on rock musicians' health-promoting behaviour, pre-performance behaviour alongside musicians' physical and mental stress experienced in low- and high-stress conditions.

Simulation and virtual reality

My evaluation of the simulation developed at the Royal College of Music was a first step towards a better understanding of alternative methods for training and enhancing performance experiences. However, future studies should compare the concept of 'distributed simulation' with other simulation tools; for instance, current technologies available are the head-mounted display or the cave automatic virtual environment (Krijn et al., 2004). The head-mounted display is a head-worn helmet that generates virtual objects in front of the eyes. The cave automatic virtual environment is a performance space of computer-projected screens using tracking systems. Current tracking systems can be divided into three categories: magnetic, acoustic or visual trackers. All three use different types of data detection, yet they all encompass a source (i.e., emitter), sensors (i.e., receivers), and a control station. For the magnetic tracker, magnetic fields are picked up by the sensors and fed back to the control station in order to calculate the position and orientation of the user within the system. The advantages of magnetic trackers are their relatively small sensors, their non-sensitivity towards acoustic interference, their high update rate and low latency, as well as their off-the-shelf availability (Mazuryk & Gervautz, 1996). Disadvantages include possible distortion by metal units as well as the requirement of a relatively close distance between the user and the tracking system. Acoustic trackers, by contrast, use ultrasonic waves above 20 kHz for data transmission. Advantages of acoustic trackers include their small size as well as their compatibility with magnetic interferences. Disadvantages include inaccurate measurements due to noise or echoes, as well as a low update rate (compared to magnetic trackers). Visual trackers can be applied in various forms, including LEDs (i.e., beacon trackers), or laser ranging—laser lights that capture the body's surface via diffraction grating. Both offer high update rates and are not sensitive to magnetic, metallic or acoustic objects. Their main disadvantage, however, is their complex construction as well as their difficulty with tracking more than one person at the same time (Mazuryk & Gervautz, 1996). Nevertheless, in contrast with the 'distributed simulation' and the head-mounted display, the computer automatic virtual environment offers (1) a higher resolution of images without geometric distortions, (2) a decrease in stimulus-latency, and (3) the capability of successive refinement between the user's performance and the virtual feedback.

To put this into context, Kim, Rosenthal, Zielinski, and Brady (2012) compared the impact of different virtual environment technologies on emotional arousal and task performance. To induce emotions during the task performance, they used the Stroop task under low- and high-stress conditions with 53 participants. The responses to the virtual environments were validated in three systems, namely a desktop system, head-mounted display, and a computer automatic virtual environment with a six-wall construction. Physiological and psychological markers of stress and the perception of immersion were assessed by means of self-reported emotional arousal and valence, skin conductance, task performance, presence and simulator sickness.[9] The results showed that the computer automatic virtual environment induced the highest level of immersion and positive emotion, while the head-mounted display triggered the highest amount of simulator sickness and negative emotions. The physiological responses showed mixed results. As such, the authors concluded that '...different virtual environment systems may be appropriate for different scientific purposes when studying stress reactivity using emotionally evocative tasks' (Kim et al., 2012, p. 267). For instance, while the cave automatic virtual environments could be applied in studies examining the impact of relaxation treatments on stress responses, head-mounted displays could be a valuable tool for effectively treating anxiety disorders in psychotherapeutically developed settings (Kim et al., 2012).

Future studies should therefore apply the concept of various simulation-training environments to address performance stress and performance enhancement and to compare the benefits of 'distributed simulation' and other technologies, such as head-mounted displays and cave automatic virtual environments.

[9] Simulator sickness is triggered by inaccurate latency feedback as well as frame rate (Mazuryk & Gervautz, 1996).

Simulation and sensory feedback

How well simulation training is perceived by users usually depends on two features: the users' characteristics, such as their cognition, expectations or personality, and the technology used (Parsons & Rizzo, 2008; Sas & O'Hare, 2002; Schubert et al., 2001; Wallach, Safir, & Bar-Zvi, 2009). Both facilitate the feeling of presence, which is '. . . the subjective experience of being in one place or environment, even when one is physically situated in another' (Witmer & Singer, 1998, p. 225). In other words, an increased degree of presence comes with an enhanced ability to 'overlook' or 'neglect' the knowledge of the artificial aspects of simulated performance training. This depends on the technology used and the application of adequate sensory feedback, such as vision, hearing, touch, smell and taste.[10]

Vision, for instance, is the most dominant and important sense, enabling an organised perception of motion, size, shape, distance, relative position and texture (Downtown & Leedham, 1991). To perceive an object as three-dimensional, several features have to be considered: luminance, brightness, contrast, the visual angle and acuity, as well as the visual field. Luminance describes the light reflected by an object; brightness refers to the light's perception; contrast represents the relationship between the light rendered from an object and the surrounding background. All three gather information about the object, including depth, texture and angle. To put this into context, an object with specific light and distance generates a certain angle, which can be measured in minutes or seconds of arc. Human-computer interfaces are considered as sufficient if the visual angle is at least 15 min of arc (which is equivalent to 4.3 mm viewed from 1 m [considering the size and the layout of the display]). If the simulation allows the head and eyes to move freely (assuming a normal flexibility of the neck), then the binocular vision is known to range between 100 degrees (°) and 120° (of a straight-ahead position), while monocular vision is represented by 360°. For a simulated environment, the ideal view is $\pm$ 90°, with $\pm$15° for a straight-ahead position. Another aspect is colour, which is nothing more than visible light observable between spectrums of 400-700 nanometers, which allows us to differentiate approximately 128 colours (consider-

[10]Taste and smell are classified as human senses, yet have not been applied in research on simulation training, mainly because these two senses are not part of humans' primary senses.

ing constant luminance and saturation). Precise colour discrimination is only available in a straight-ahead position of $\pm 60°$, while a general awareness of colours increases the field to $\pm$ 90°.

Hearing is the second most important human sense. Its perception ranges from 20 −20.000 Hz, but functions best within 1000 −4000 Hz (Normal conversations are held between 50 dB and 70 dB, but are affected by background noises and individual confounders such as age and hearing conditions.). Unfortunately, sound is not as investigated or implemented in simulations as visual feedback due to the complexity of generating authentic auditory feedback (Gaver, 1997).

The impact of sensory feedback on the perception of simulation training and learning outcomes has been examined by Larsson, Västfjall, and Kleiner (2001). In particular, they assessed the learning effects of stimuli, including visual feedback or both visual and auditory feedback, while participants had to perform two memory and navigation tasks. The effect itself was measured by the time spent solving the tasks. The results demonstrated a superior outcome for the visual and auditory feedback in terms of time, but also an increased degree of presence. In a follow-up study, Larsson, Vastfjall, and Kleiner (2002) investigated the relationship between presence and auditory stimuli. For this, participants were asked to rate their level of presence, their awareness of external factors, and their simulation sickness (an indicator of a higher level of immersion). The results showed that the bimodal mode had a significant impact not only on the time spent solving the task but also on enhanced feelings of presence, focus and enjoyment. In a second study, the auditory stimuli were moreover divided into low versus high quality. The results showed that participants exposed to greater auditory fidelity showed higher levels of presence, although the higher quality of the audio stimuli did not produce better performance outcomes.

Other studies, such as the one by Lokki and Gröss (2005), compared visual, auditory and audio-visual cues by using a simple game-like application where participants were asked to navigate a point through gates on predefined tracks. The tracks were presented using visual, auditory or audio-visual cues in a three-dimensional space. The success was evaluated by the number of gates found, the time spent searching for these gates, and the path length. The results had a significant effect on the sensation of presence by means of audio-visual cues compared to either auditory or visual cues.

In simulations, the main purpose of sound is to deliver information from the object in order to increase the tangibility of the virtual system. The development and application of auditory feedback is not expensive and creates a compelling experience regardless of the quality of the visual display. To ensure an authentic experience, it is important to define the direction and the distance from which the sound comes (equivalent to the visual feature of depth created by luminance). The 'illusion' of directional sound can either be recorded or generated. This is achieved by recording sound for the left and right ears (using headphones) or by presenting the user with sound sources recorded from the environment (using speakers). Furthermore, additional features have to be highlighted, such as inter-aural delay, differences in amplitude between ears, the size, volume and characteristics of the environment (e.g., masking the effects of furniture, noise pollution, etc.), the body's occlusion of certain frequencies, and the filtering processes of the outer ear. In addition, if the simulation training requires free head movements, additional signal-processing steps must be implemented for compensation (Mazuryk & Gervautz, 1996).

Besides vision and hearing, another factor that has to be considered in simulations is touch, encompassing the concepts of kinaesthesia (Mazuryk & Gervautz, 1996). Kinaesthesia is the perception of the movements, muscles and joints of the body, while touch senses the skin's surface, providing the perception of temperature (i.e., thermoreceptors), pain (i.e., nocioreceptors) and pressure (i.e., mechanoreceptors). For simulation training, mechanoreceptors are of most interest because they respond to vibration, skin stretching, velocity or flutter, and skin curvature. To put this into context, haptic devices used in simulation training have to be constantly stimulated in order to avoid sensorial adaption, and it is necessary to consider pressure detection (absolute threshold), location, type of stimulation, size of contact field, stimuli frequency, and active or passive exploration. Similar to visual and auditory cues, technological properties, such as fidelity, spatial and temporal resolution, latency tolerance, and size, have to be taken into consideration (Sherman & Craig, 2003, p. 180). Haptic devices were first introduced by computer mice and joysticks developed in the video game industry to provide vibro-tactile feedback to the user. Ever since then, haptic devices have experienced technological progression (Hayward, Astley, Cruz-Hernandez, Grant, & Robles-De-La-Torre, 2004; Laycock & Say, 2003), including pen-based devices and gloves.

The application of haptic devices has so far been implemented in fields such as medicine; Burdea, Patounakis, Popescu, and Weiss (1999), for example, used a pen-based device to enhance the trainee's skills at detecting malignant versus non-malignant prostate cancer. The pen provided feedback to the index finger throughout the training session, and after five 12 min sessions, participants' rate of diagnoses increased—compared to a control group—by 67%. Morris, Tan, Barbagli, Chang, and Salisbury (2007) compared haptic training, visual training and visual-haptic training to memorising structured force patterns. Participants were asked to recall a sequence of forces (72 trials, including a break after 36 trials) with 24 trial blocks for each condition. The analysis was based on the accuracy (i.e., force pattern) as well as the time needed to recall the presented target (recreating a curve). A comparison between each condition revealed that the most efficient recall occurred with visual-haptic training, followed by visual and then haptic training.

The sense of smell is perceived by the biochemical and electrical signals transmitted from the olfactory receptors and nerves, respectively, located in the upper part of the nostrils (Zybura & Eskeland, 1999). Reaching the amygdala and the hippocampus, the signals are evaluated in terms of: (1) an intensity estimation; (2) qualitative description; (3) a hedonic tone. The intensity estimation evaluates the scent's strength (and facilitates its localisation), while the qualitative description refers to the odour detection. Needless to say, they also depend on cognition, cultural background and past experience. The hedonic tone classifies an odour as pleasant or unpleasant and is determined by concentration and intensity, as well as cognition, cultural background and past experience. In contrast, the perception of taste is processed by 'taste buds', '. . . [aggregating] 50-100 polarised neuroepithelial cells that detect nutrients and other compounds' (Chaudhari & Roper, 2010, p. 285). Though taste and smell are sensed by different organs, their signals are perceived in combination (e.g., flavours, food recognition).

Simulation, including the application of olfactory stimuli, is rather rare due to technological challenges. Displays need to be adjusted in terms of fragrance density and distinction, adequate temporal duration of exposure, mixture of diverse fragrances after continuous usage, and also personal characteristics (e.g., middle-aged individuals tend to have an increased sensitivity to smell compared to their younger or older counterparts: Davide, Holmberg, & Lundström, 2011). Thus far, simulation with olfactory displays have only been used as part of an intervention study. This was, for instance, done by Kaganoff, Bordnick, and Carter (2012). The authors assessed 49 heavy smokers classified by the DSM-IV by means of presenting nicotine cues for pre- and post-test assessments in the virtual environment. After 10 weeks of nicotine replacement, participants wore a head-mounted display and entered one neutral and two smoking environments (i.e., 'smoking paraphernalia' versus 'smoking party'). In each scenario, participants had to fill out a Smoking Attention Scale (Hutchison et al., 2001), assessing the degree to which they had the desire to smoke a cigarette. Olfactory cues were presented by the Scent Palette (Environdine Studios, Atlanta, GA), exposing scents controlled by the virtual-reality software. While the neutral stimuli delivered scents of fresh flowers, the smoking olfactory stimuli were a combination of cigarettes (smoking paraphernalia) and raw tobacco and pizza (smoking party). The results showed that participants' nicotine reactivity (i.e., increased attention and thinking towards nicotine cues) was significantly higher during the two smoking stimuli compared to the neutral stimuli, suggesting that olfactory stimuli using simulation can be used to assess and improve users' smoking behaviour.

In the field of music performance science, future studies should investigate the benefits of specific visual, auditory and haptic feedback in simulation training in order to enhance musicians' performance skills, and also to increase musicians' sensation of 'presence' (Tellegen & Atkinson, 1974).[11]

[11] The degree of presence was first examined by Tellegen and Atkinson (1974), who designed a questionnaire attempting to measure the level of one's absorption, defined as a disposition towards experiencing phases of 'total' attention in regard to perceptual, imaginative and ideational resources. The questionnaire assesses the degree of openness to new experiences to a variety of different situations. People more likely to be immersed show enhanced focus, are less easily distracted by objects or events, and are able to change focus based on the situational requirements (Tellegen & Atkinson, 1974). This reflects the cognitive ability to sense and imagine experiences and to alter perceptions through behavioural and biological adapted responses (Menzies, Taylor,

The simulations in this thesis were tested to ensure that they are credible, appropriate and effective. Specifically, I assessed the realism of the scenario (face validity). Nevertheless, future studies that aim to develop simulation training for musicians should consider that a realistic simulation scenario should contain an increased degree of interactivity, three-dimensionality, accurate details (object projections), high resolution (fidelity), adequate sensory input and reactivity.

Only by encouraging researchers to address each of the points mentioned above will we be able to determine the most effective way to train musicians using simulation training as an educational tool for enhancing their performance experience.

8.4.2 Practical considerations

Performance stress and physical exercise

An interesting and relatively underdeveloped area of research is the impact of stress reducing interventions, such as physical exercise and musicians' overall stress responses. Surprisingly, not many studies have evaluated the effect of physical exercise on musical performance stress, even though its benefits have been shown in other domains (Hamer & Steptoe, 2007; Klaperski, von Dawans, Heinrichs, & Fuchs, 2013, 2014; Steptoe, Kearsley, & Walters, 1993) and its application is straightforward and relatively easy to apply.

Physical exercise has been shown to benefit cognitive functioning (Carek, Laibstain, &

& Bourguignon, 2008). Tellegen's absorption scale examines a variety of tendencies, such as '... (a) the responsiveness to engaging with stimuli, (b) the responsiveness to inductive stimuli, (c) imagistic thoughts, (d) the ability to summon vivid and suggestive images, (e) cross-modal experiences (e.g., synaesthesia), (f) absorption in thoughts and imaginings, (g) vivid memories of the past, (h) episodes of expanded awareness, and (i) altered states of consciousness' (Glisky, Tataryn, Tobias, Kihlstrom, & McConkey, 1991, p. 264). Studies that use the Tellegen Absorption Scale have been predominantly applied in the medical field. For example, Kenny (2009) administered the scale to evaluate how efficiently and believably clinicians experience interactions with a virtual patient based on a training programme. The results showed a moderate correlation between the Tellegen Absorption Scale and the perception of virtual 'reality'. Another study by Wiederhold et al. (2003) compared physiological responses such as heart rate and skin resistance and the Tellegen Absorption Scale in a flight simulation. The study was part of an intervention and compared the effectiveness of simulation training amongst phobic and non-phobic patients. Interestingly, the results showed that (a) phobic participants perceived the virtual environment as more realistic than non-phobic participants, and (b) there was a significant correlation between participants' heart rates and subjective experiences of absorption.

Carek, 2011; Vancampfort et al., 2011), cardiovascular functioning (Blumenthal et al., 2005; Hambrecht et al., 2003) and stress management (Brownley et al., 2003; Chafin, Christenfeld, & Gerin, 2008).

Defined as '…participation in a program of regular, structured, physical exertion of varying degrees of intensity designed to increase heart rate and/or muscle strength' (Edenfield & Blumenthal, 2011, p. 300), two types of exercise exist: aerobic and anaerobic. Aerobic exercise implies activities used with oxygen, such as brisk walking or jogging, supplying the cells with energy. Anaerobic exercise triggers lactic acid formation, a process by which enhanced metabolism of muscle glycogen occurs, building up muscle mass (Lippincott & Wilkis, 2014). This is produced by a high intensity workout, such as weight lifting or sprinting. Aerobic exercise is especially believed to facilitate a cross-stressor adaption (Sothmann et al., 1996), an increased tolerance towards familiar and novel physiological and psychological stressors. These adaptions are also assumed to reduce the sympathetic nervous activity and increase the parasympathetic nervous activity.

Indeed, stress research overall confirms the positive effect of exercise on physiological and psychological responses to stress; yet, it is still debated which type, frequency, and duration of physical interventions optimise physical and mental responses to performance stress. Petruzzello, Landers, Hatfiled, Kubitz, and Salazar (1991), for instance, examined in a meta-review the relationship between various types of anaerobic and aerobic exercises (e.g., weight-training versus walking, swimming) and state and trait anxiety inventories (e.g., Spielberger et al., 1983). He reviewed 104 studies, considering the categories: (1) exercise (aerobic vs. non-aerobic, duration and intensity of the exercise carried out), (2) design of the study (pre-post-/multiple-assessment, control versus comparison group (e.g., meditation, relaxation), and (3) type of participant (age and mental health status). Based on 408 effect sizes and a sample size of 3048 participants, the results showed a significant overall relationship between exercise and state anxiety reduction from pre-test to post-test interventions after aerobic but not anaerobic exercise. Both acute and chronic exercise was equally effective, yet, compared with other interventions, such as yoga, the effect diminished. Higher exercise intensity (measured in $\%HR_{max}$ or $\%VO_{2max}$ caused greater reduction in state anxiety, while the time the state anxiety inventory was administered (<5 minutes versus >20 minutes) did not have an impact. In terms of exercise and trait anxiety, a significant overall response between exercise and anxiety reduction was observed, with again, a significant effect for aerobic, but not anaerobic exercise. This outcome remained stable when other interventions were considered. Higher exercise intensity (measured in $\%HR_{max}$ or $\%VO_{2max}$) carried out for at least 20 minutes produced greater changes in anxiety reduction, especially in participants: (1) suffering from high levels of anxiety; and (2) between 31-45 years.

Long and Stavel (1995) conducted a meta-review where they investigated the effect of exercise carried out at least 3 times per week, 20 minutes in duration, over a period of six weeks. Exclusion criteria were participants under 18 years and non-standardised physiological and psychological measures. Inclusion criteria were: (1) experimental or quasi-experimental studies; (2) within versus within-between subject designs (pre-test versus post-test; pre-test versus post-test versus experimental versus control group); and (3) self-reports on state and trait anxiety that fulfil psychometric criteria (e.g., reliability and validity). Twenty-six studies investigating pre-test versus post-test effects and 20 studies comparing exercise with other interventions, such as yoga, were selected. The pre-test and post-test comparisons revealed: (1) a significant overall effect between exercise and anxiety reduction; (2) a greater impact for higher than lower anxious participants; and (3) a greater effect for men than for women. The effect of exercise on state and trait anxiety outcome was similar, with shorter interventions (6-8 weeks) producing a greater impact than long-term interventions (>12 weeks). Weekly sessions of between one and three sessions tend to be more effective than more than three times though this could be linked to participant compliance issues. In terms of exercise during contrast group assessments (between groups with pre-test and post-test assessment), results showed: (1) a significant overall effect between exercise and anxiety reduction; (2) a greater impact for higher than lower anxious participants; and (3) greater results for men than for women. Shorter intervention (6-8 weeks) produced a greater anxiety reduction than long-term interventions (>12 weeks), and weekly sessions performed three or more times were more effective than those carried out less than 3 times.

Last, Conn (2010) examined the relation between exercise (e.g., supervised [educational or motivational] exercise sessions) and anxiety reduction among healthy participants on a long-term basis. He selected 19 studies published between 1983 and 2008. Exclusion criteria were: (1) participants with mental disorders; and (2) studies that did not measure the long-term effect of exercise on anxiety. Studies were coded with regards to sample size, participants' characteristics, methods, and type of interventions applied. Results demonstrated significant effects between physical exercise and anxiety reduction, while the time self-reports were collected did not significantly change the anxiety outcome (<90days); however, group intervention was significantly less effective than exercise on a one-to-one basis, as well as when exercise was carried out in lower rather than higher intensity. The impact of exercise on anxiety reduction was reinforced by supervised training compared with unsupervised training, as well as when carried out in a gym rather than at home.

Based on these reviews, it can be concluded that exercise causes a noticeable, yet heterogeneous effect on anxiety. Such discrepancies were linked with variation in: (1) type, lengths, and frequency of exercise; (2) exercise compared with other interventions; (3) age; and (4) gender, with older and male participants experiencing greater benefit than their younger and female counterparts.

In the musical domain, only Wasley, Taylor, Backx, and Williamon (2011) investigated musicians' degree of physical fitness and its impact on performance stress; they assessed 46 musicians on two days, one week apart. During the first unit, height, weight, baseline heart rate, blood pressure, state anxiety, as well as musicians' perceived physical activity, were taken. In addition, a cycling test at 60, 90, and 120 Watt was conducted. The index of physical fitness was expressed in VO_{2max}, known as the maximum rate of oxygen consumption during gradually increasing exercise. In the second unit, musicians performed in front of a jury with the possibility to win a prize based on the performance quality. Scheduled 20 minutes prior to the performance, musicians' blood pressure was taken 15, 10, and 5 minutes before the performance, while ECG was monitored throughout. Subjective feelings of anxiety was assessed before and after. Results showed that musicians ranged 'normally' on the BMI index and did approximately 210 minutes of moderate to vigorous sport per week. Anxiety, heart rate and blood pressure were significantly elevated during the pre-performance period in the high-stress condition, though no specification of the outcome between the three measure point (15, 10, and 5 minutes) was provided. The degree of fitness was positively correlated with heart rate (variability), while a negative correlation between fitness level and state anxiety occurred. Fitter musicians exhibited a more pronounced decrease in state anxiety during the post-performance period, suggesting an association between fitness and psychological recovery.

Musicians need to have excellent commands over their physical and mental skills in order to deliver an adequate performance. This requires a sufficient state of physiological and psychological health and wellbeing. Future studies should employ simulation training and physiological signal processing methods in combination with physical exercise as an intervention to reduce performance stress before, during and after the performance. The simulation developed at the Royal College of Music would be an ideal platform to assess its benefits in a standardised and controlled environment. Educational institutions, such as conservatoires, should therefore be encouraged to supply musicians with specifically tailored physiological and psychological screening tests in order to identify adequate training programmes that address and improve physical endurance towards performance stress. (Ginsborg et al., 2009).

Performance stress and Alexander Technique

Performance stress and the application of the Alexander Technique is another valuable prospect for further research in performance science. Compared to physical exercise, the Alexander Technique is a well-established part of conservatoire's educational programmes. Nevertheless, the benefits of the Alexander Technique are yet to be fully understood, especially when aiming for the reduction of performance stress.

Thus far, the Alexander Technique is known to be a re-educational approach that has a long tradition in music education. It is supposed to improve the balance between body, mind and the emotions and thus an ideal tool to work on performance stress (Kleinman & Buckoke, 2013). By applying principal guidelines based on self-observation, the Alexander Technique has been applied to a variety of other health conditions, such as chronic back pain, respiratory problems, or mental tension.

An early study that investigated the benefits of Alexander Technique was carried out by Austin and Ausubel (1992). They evaluated the impact of Alexander Technique based on self-reports and respiratory functioning. Fifteen Alexander Technique teachers recruited one of their students without respiratory problems, no smoking history, and standard body weight. As a pre-test-post-test-comparison, a spirometer, measuring the volume of air expired/inspired was applied twice seven months apart. Results showed a significant improvement of respiratory muscular strength (e.g., peak expiratory flow, maximal inspiratory/expiratory mouth pressure) and endurance (i.e., maximal voluntary ventilation), while such increase was not observed in the control group.

To strengthen these outcomes, Little et al. (2008) did not only examine the impact of the Alexander Technique on subjective physiological improvement to no treatment, but also in contrast to other interventions, such as massage therapy or Alexander Technique alongside with aerobic exercise. A sample of 579 participants with chronic or recurrent back pain was assigned randomly, receiving either six sessions of massage (n=147), 24 Alexander Technique lessons, or six lessons of Alexander Technique (n=144). Half of each group was randomized to prescribed aerobic exercise—behaviourally counselled by a medical team. The subjective perception of physiological improvement was measured by the Roland Morries Disability Questionnaire (Roland & Fairbank, 2000). Results revealed a significant positive effect for both the Alexander Technique group and the Alexander Technique intervention in conjunction with aerobic exercise, while no improvement was observed for the massage therapy.

Cacciatore, Gurfinkel, Horak, Cordo, and Ames (2011) collected not only self-reports, but also objectively compared the postural tone between Alexander Technique teachers (n=14) and a control group (n=15). They also investigated the impact of 10 weeks of 45-minute one-to-one Alexander Technique sessions in participants with lower back pain (n=8). Results demonstrated Alexander Technique teachers—compared to their control group—exhibiting greater flexibility in postural dynamic by a lower torsional resistance to rotation (peak-to-peak, phase-advance, and variability of torque) compared to the control group. The positive effect of Alexander Technique was also shown for the intervention group, having led to a decreased trunk and hip stiffness. Reddy et al. (2011) investigated alongside changes in poster, respiration heart rate and blood pressure. Seven participants received two Alexander Technique group sessions as well as six, 45-minutes, one-to-one lessons. Self-reports included the perception on respiration and ergonomic quality. Results demonstrated a significant improvement not only of perceived respiration and body alignment, but also in monitored resting respiratory rate and peak inspiration chest circumference. However, no other significant changes (e.g., heart rate, blood pressure) were found.

In the musical domain, Alexander Technique was first applied by Barlow (1956), photographing 50 students at the Royal College of Music from the front, side and back before and after half of them received Alexander Technique lessons (no indication of the amount or type was given). The posture was defined by 5 categories: excellent posture ('0-3'); moderate to severe defects ('4-9'); severe defects ('10-14'); and gross postural deformities (>14). Results showed an average decreased postural fault from 9 to 4 in female and from 11 to 5 in male students. However, neither a detailed protocol on the approach used was provided nor were statistical analysis carried out.Jones (1972) applied Alexander Technique by adjusting the neck position in a singer while being audio recorded. A subsequent spectral sound analysis showed a greater richness in overtones as well as improved breathing patterns before and after the postural re-education. A peer student audience's feedback supported this effect, albeit this study only represents a case study and needs further verification with a bigger sample. Bosch and Hinch (1999) documented each step of their un-supervised treatment sessions in two flute players suffering from shortness of breath, lower back pain, and tension in shoulders and neck. Although no statistical analysis was carried out, they emphasised that Alexander Technique '... [may have] bodily and spiritual benefits ... [and] ... positively effect one's whole life' (Bosch & Hinch, 1999, p. 51). Brandes and Dionne (2008) determined the effect of Alexander Technique in a secondary school choir after eight 20-minute lessons over a period of six weeks. Semi-structured interviews, observational notes as well as two videotapes assisted the analysis. Results demonstrated an expanded awareness of (the interconnection between) body and mind, as well as noticeably elevated energy—all of which was reported to be attainable with minor effort. These results, however, were not backed up by any objective or physiological measures making the work open to many criticisms i.e., participant bias.

In terms of Alexander Technique sessions and their impact on the reduction of performance stress, only sparse evidence exists. Valentine, Fitzgerald, Gorton, Hudson, and Symonds (1995) randomly assigned 25 music students to either 15 Alexander Technique lessons or a control group. Questionnaires administered were the Performance Anxiety Inventory (PAI: Nagel, 1990), the Eysenck Personality Inventory (EPI: Eysenck & Eysenck, 1964), the Mood adjective checklist (Nowlis, 1965), and the Anxiety Self-Statements (Craske & Craig, 1984). In addition, they were asked to rate their degree of interest in having Alexander Technique sessions (1='Prefer not' to 4='Very interested indeed'). Musical sessions assessed included: (1) an audition; (2) a final recital; and (3) two performance classes—one held before the treatment and one after, including a performance in front of peers and their teacher. Heart rate was monitored (at 10-second intervals) two minutes before each session. Results showed a significant relationship between neuroticism and the wish to attend to Alexander Technique sessions, and a significant improvement in the Music Anxiety Self-Statements as well as the

Mood adjective checklist between the two performance classes while an opposite pattern was observed for the control group. Nevertheless, no significant difference was found between audition and final recital. High-stress performances produced greater heart rate than the low-stress condition, yet no main effect or interaction between groups was detected. Furthermore, calculated standard deviations of the heart rate were greater for the control group prior to the final recital, yet no difference between the two performance classes was found.

Valentine and Williamon (2003) assigned musicians of different instrumental backgrounds to either Alexander Technique (n=10) or alpha-theta neurofeedback (n=8). Alexander Technique training was carried out weekly, including 12 30-minute one-to-one units, while neurofeedback was conducted 10 times for 15 minutes over 6 to 8 weeks. The State and Trait Anxiety Inventory-state form (Spielberger et al., 1983), was administered before and after the interventions. Each performance was audio and video recorded and rated by two external experts (blinded to group assignment) in terms of head-neck-back relationship, use of upper limb/back, use of hips/balance, direction of knees, face and eyes, breathing, fingers, use of inhibition, overall impression, as well as the performance quality (1='Very poor' to 7='Excellent'). Results showed a significant decrease in the State Anxiety Inventory before and after the training in both groups. Furthermore, while the posture (head-neck-back relationship; upper limb/back; face and eyes; fingers; thought direction; inhibition and overall impression) was significantly improved after the Alexander Technique, a decline was found for the neurofeedback group. No difference in performance quality was observed.

Studies that have investigated the impact of the Alexander Technique on musicians' performance stress response have shown moderate effects, with evidence exhibiting noteworthy limitations: firstly, most of the studies only encompassed single cases (Bosch & Hinch, 1999; Jones, 1972). While case studies offer meaningful insight into a research area where little knowledge exists, it provides only a limited spectrum of meaningful insight as the results are not applicable for valid generalisations. Secondly, many studies used qualitative methods only (Brandes & Dionne, 2008); the application of interviews are beneficial if researchers want to find out more about the subjective perspective on a subject that is hardly explored.

However, similar to the case studies, it provides results that are biased through the lack of more objective and generalisable methodologies. The Alexander Technique is holistic body-mind approach and thus, both physiological and psychological assessment tools should be considered to understand the real impact of such intervention. In particular, future research should be encouraged to carry out a close examination between the link of Alexander Technique and cardiovascular stress responses in response to different performance contexts.

Performance stress and mental skills training

Mental skills training (i.e., mental preparation) is the cognitive rehearsal of a performance in absence of the physical movement and sound (Driskell, Copper, & Moran, 1994) and includes physical and mental relaxation (visualisation, reduction of muscle tension), attention focussing, positive imaginary, self-efficacy statements and other forms of mental, physical or emotional regulation during practice or prior to a performance (Williamon, 2004). It is therefore an ideal tool to further investigate physiological and psychological performance stress.

Music making involves complex cognitive elements (not unlike most disciplines in sport) and the quality of output can be assessed objectively (Bernardi et al., 2013). Musicians are encouraged to apply aural, visual, and kinaesthetic visualisation, as well as cognitive (specific skills rehearsal) and motivational strategies (emotional regulation) that leads to a performance sensation that similar to a real performance experience (Gregg & Clark, 2007; Williamon, 2004). Thus far, Gregg and Clark (2007) were two of the first who aimed to discuss mental imagery in the musical context. Emphasising the successful implementation of mental imagery training applied in sport psychology, such as the importance of cognitive (specific skills rehearsal) and motivational functions (emotional regulation), Gregg and Clark developed an adaptive model for musical performance preparation, with particular focus on the performance situation (rehearsal versus performance). For the musical context, they identified several features to mentally prepare for a performance, such as the importance of practicing structured auditory imagery and performance confidence.

Recent studies that addressed the efficacy of mental reparation in the musical domain stems from Highben and Palmer (2004). They asked sixteen pianists to mentally rehearse four novel 20-minute pieces over ten practice trials. The practice trials included: (1) normal practice; (2) practice without auditory feedback (sound turned off but still pressing the keys); (3) practice without motor feedback (not pressing the keys but hearing a recording of the piece); and (4) mental practice in the absence of auditory and mental feedback. Results showed that the removal of any feedback lowered learning and memory abilities, and that normal practice provided the most efficient performance outcome. In addition, pianists who possessed greater aural skills were less affected by the missing feedback during practice than those without.

Clark and Williamon (2011) assessed mental preparation through the lens of self-regulated learning behaviour and compared mental training between an experimental and a control group and its impact on anxiety (Spielberger et al., 1983), self-efficacy (Ritchie & Williamon, 2011) and performance quality (overall quality, technical proficiency, musical understanding, communicative abilities, etc.). Twenty-three music students volunteered for this project, with 14 assigned to the experimental group and nine to the control group. Students completed questionnaires on self-regulated learning (Zimmerman, 1998) and their perception of musical skills (Ritchie & Williamon, 2011) and mental skills (Sheehan, 1967). The intervention was carried out over nine weeks, including one 60-minute group session and one 30-minute individual training unit per week. During these session, awareness was raised for the topics: goal-setting, effective practice (performance preparation/analysis) and time management, relaxation strategies and self-talk, mental imagery, focus and concentration, to name but a few. The results revealed a significant improvement in musical learning and self-regulation and in the ability of mental imagery compared with the control group. Likewise, self-efficacy increased, while no significant changes in state and trait anxiety was reported. In another study, Clark et al. (2014) could demonstrate that musicians, in order to achieve a successful performance through mental preparation, emphasis on the imagination of specific performance features, such as sound, physical execution and musical expressivity, but also a sufficient 'performance-sensation,' musicians define through an increased control over performance anxiety and outcome.

Bernardi et al. (2013) assessed mental practice and musicians' progress on music memorisation using mental practice strategies of individually preference. Sixteen pianists were asked to memorise two pieces by applying either physical practice or mental practice. Performances were evaluated in terms of correctness of notes, articulation and phrasing, dynamics and expressions, and via a global performance quality score. Results showed an improved musical learning using mental practice as well as mental practice alongside physical practice, which was also supported by the external performance quality ratings (inter-rater reliability=.58-.79).

Last, an extensive evaluation of mental skill preparation was carried out by Osborne, Greene, and Immel (2014). In particular, the efficacy of the performance success programme by Greene (2002) was put under scrutiny.[12] Osborne et al. (2014) asked thirty-one classical music students to attend to training sessions twice a week over a three-weeks course, followed by one week instrument-specific training. During the course, musicians learned how to effectively reduce performance anxiety, to achieve their personal performance goals and to acquire seven performance-enhancing strategies based on the performance success model. To evaluate the benefits of the program, musicians completed a performance skills inventory (also developed by Greene) before and after the intervention. The results revealed substantial improvement in the ability to learn, to apply positive self-talk habits, to confront fear, to get mentally quiet and to concentrate on demand. Conversely, no improvement was observed for energy regulation and performance anxiety reduction.

Mental skills training encompass the successful rehearsal of cognitive tasks, such as conducting a formal analysis of the score, to listen to recordings and to develop an auditory

[12] Based on eleven performance success strategies drawn from different performance domains, Greene considered four essential preparation strategies: (1) the identification of a clear goal (e.g., performance outcome); (2) an increased body awareness to reduce tension tendencies and the channel of body energy to facilitate perform-readiness; (3) efficient breathing techniques (e.g., abdominal breathing instead of chest breathing to release tension and facilitate relaxation); and (iv) conscious attention shift away from the left brain hemisphere, which is a '... major obstacle to achieving the mental quiet necessary for optimal performance [...]' (Osborne et al., 2014, p. 7). Thus, specific performance success strategies ranged from the ability to centre and control the performance energy through positive self-talk habits to the empowerment of performance confidence, courage and resilience.

imagine of the repertoire and physical movement involved (Köppel, 1996). Like the Alexander Technique, mental skills training is a body-mind approach (Williamon, 2004) and should therefore assessed in a holistic framework. This should include a weekly programme that allows for a thoroughly preparation of musicians' mental skills and the application of both simulation training and physiological assessment to evaluate the impact of mental skills training on both the musicians' body and mind.

Performance stress and self-regulation

Another interesting approach to reduce performance stress is the concept of self-regulated learning. Music making is an activity with high physical and mental demands (Clark & Williamon, 2011) and it is therefore increasingly important to recognise how musicians can maintain a healthy physical and mental state in order to secure a lengthy career. A critical stage in a musician's development occurs during higher education (e.g., conservatoire) where they train and prepare to enter the musical profession. In these surroundings, musicians usually practice thousands of hours to achieve a skill set that is similar to mastery levels (Ericsson et al., 1993). However, while the time and amount of preparing has certainly received been subjected to increased scrutiny, noticeable less work has been done in understanding how to recommend musicians to prepare effectively and thus, reduce the likelihood of experiencing performance stress (Williamon, 2004).

Practicing is the most common activity of musicians during and beyond their musical education (McPherson & McCormick, 2006). Practice involves a combination of effective training strategies, such as skill acquisition, developing and performing repertoire, techniques (e.g., scales, etudes) and musicianship (e.g., improvisation, sight-reading: Klickstein, 2009). This has been shown to be best achieved through the concept of self-regulated learning, defined as activities that include 'self-generated thoughts, feelings, and actions for academic goals' (Zimmerman, 1998, p. 73). Self-regulated learners show an enhanced participation in metacognitve and motivational strategies by means of applying specific, personally adapted, and proactive processes that are tailored-made to the given task. Research reveals that the concept of self-regulated learning includes six important dimensions for a successful performance outcome, including motive, method, time management, behaviour, physical environment, and social factors (McPherson & McCormick, 2000; McPherson & Thompson, 1998). Investigating these aspects research could, in general, demonstrate that '... strategic, purposive, and reflective approaches to practicing are: (1) likely to develop over a long time; (2) motivated primarily via intrinsic sources, and (3) more likely to yield performance competence' (Miksza, 2011, p. 323).

Research investigating the link between self-regulation and musical performance and learning has demonstrated quicker skills acquisitions, a greater motivation to practice and overall better performance outcomes. Williamon and Valentine (2000), for instance, conducted a systematic observation of twenty-two piano students while learning new repertoire. The quality of the pianists' practice sessions directly impacted on their final performance assessment and was independent of the amount of time spent practicing. Similarly, McCormick and McPherson (2003) asked musicians about their motivational and self-regulatory features of instrumental performance. The results showed that high musical achiever employed more self-evaluation and mental rehearsal than low-achiever, and exhibited a greater critical judgment of the success of their practice efforts.

Also, Hallam (2001) investigated the effect of self-regulated learning in novices and professionals by interviewing as well as recording their practice habits. The results suggest that professional musicians demonstrate—compared to novices—much better meta-cognition by spending more time on planning and evaluation. Miksza (2007) evaluated effective practice behaviours, concluding that more strategic approaches resulted in better performance outcomes and, therefore, highlighted the importance of the development of perceptual skills.

Unfortunately, musicians often exceed their physical limits by intense preparation, overly strenuous repetition, prolonged playing without adequate rest and lack of warm up (Zaza, 1994), often leading to an increased risk of experiencing performance stress. Such practice behaviour not only impacts on the likelihood to develop severe practice-injury development (Guptill, 2011), but may also lead to psychological maladaptive reactions, such as an increase fear of failure and presence of performance stress (Ackermann, Kenny, & Fortune, 2011). Thus, while research has realised that the duration of practice is crucial for skill development, it is still the quality of preparation that remains central (Lehmann et al., 2007).

To develop and maintain a successful performance career, musical preparation is an indispensable part of performance enhancement. Effective musical preparation involves warm-up, enough breaks, the avoidance of massed practice of the same musical content, and the importance of stepping back from the instrument in order to apply aural, visual, and kinaesthetic visualisation that allows a performance sensation similar to practice (for more details, see 'Performance stress and mental skills training'). Daily exercise should be considered to enable increased performance stamina and a general understanding of body and mind; physically to prevent muscoskeletal injuries and mentally, to reduce performance stress and facilitate an increased performance confidence (for more details, see 'Performance stress and physical exercise.').

Thus, teaching self-regulated learning and making students aware of the advantages of applying these strategic, purposive, and reflective approaches to practising is, given the increased pressure and competitiveness in musical domain, especially relevant. As a consequence, teachers/educators should aim to encourage students to view their practice as a self-teaching activity in order to effective learning. Future studies should therefore aim to develop, alongside musicians and music teachers, a healthy practice schedule that helps musicians to overcome the daily challenge of establishing a practice routine and to decrease the experience of performance stress based on insufficient self-regulated learning strategies. In particular, they should employ the dimensions of motive, behaviour and time management in order to help musicians become aware and improve their self-regulated learning strategies by means of incorporating a practice tool musicians can use on a regular basis.

Performance stress and smartphone applications

Mobile phones are, unlike other devices such as laptops, almost always in our reach and can be found either in bags, pockets or purse, making the user available at any place and at any time (Klasnja & Pratt, 2012). According to the International Telecommunications Union in 2012, across developing countries, the average person owns 1.18 mobile phones with this number continuing to rise (Hebden, Cook, Ploeg, & Allman-Farinelli, 2012). Much of this increase has been in smartphone ownership where there were more than 490 million shipments of smartphones globally in 2011 compared to 300 million in 2010. By 2019, it is expected to have 2,659.4 million smartphone owners worldwide. This growth has been concentrated primarily in young adults between 25-34. Each mobile phone contains sensitive personal information, ranging from imagines of and text messages from friends and family to the track daily activities, such as meetings, emails or social network behaviour. The increasing popularity of mobiles phones has led to development of a stupendous amount applications to deliver, foster and sustain health-promoting intervention and behaviour in an efficient and straightforward fashion. In particular, the result of smartphone popularity has led to the proliferation of smartphone software in the form of applications ('apps'). Apps provide a platform to create daily entries of behaviours, to monitor and plan around these behaviours, and to make adjustments where necessary (Schwarzer, 1999).

Apps have been designed in a variety of settings with the aim to facilitate and maintain self-regulatory behaviours in a novel way, reaching individuals en masse. In clinical health care, for instance, apps have been utilised where patients with asthma are able to monitor themselves, such as by keeping a diary of symptoms, and are afforded therapeutic feedback (Boulos, Wheeler, Tavares, & Jones, 2011; Franko & Tirrell, 2012; Klasnja & Pratt, 2012). Arsand, Tatara, Ostengen, and Hartvigsen (2010), for instance, used focus groups, interviews, feasibility testing and questionnaires to develop a smartphone application as a self-management tool for type 2 diabetes. The final application, called 'Few Touch', includes an off-the-shelf blood glucose (BG) meter, a tailor-made step counter, and software for recording food habits and providing feedback on how users perform in relation to their own personal goals. Twelve users with type 2 diabetes evaluated the app for 6 months. Results demonstrated a high degree of user satisfaction and noticeable changes in attitude towards healthy behaviour, such as changes in medication, food habits, and/or physical activity. For this, the app was able to provide them with an efficient way to capture and analyse relevant personal information about their disease noted.

In the sport domain, apps offer athletes the opportunity to structure, plan, and analyse their training by monitoring and evaluating parameters, such as speed, power, and heart rate (Kranz et al., 2013; Xu, Cheng, Zhang, Zhang, & Lu, 2009). Moreover, these information can be synchronised and shared with their coaches, allowing for close assessment of training progress.

To put this into context, Kranz et al. (2013) developed an application that introduces individualised exercise skill assessment (balance board training) by means of sensor data providing real-time feedback. Participants carried out twenty exercises with the application recording accelerometer and magnetometer data. Subsequently, they validated the application by user feedback and quantitative information processing. The results showed that the quality ratings suggested an increased motivation and a positive attitude to reach a training goal faster and that the automated skill assessment was as accurate and effective as standard expert evaluations.

On a commercial level, apps have been devised to assist weight loss with information on nutrition, physical activity, and calorie counting, and to improve dietary habits (Hebden et al., 2012; Lee, Chae, Kim, Ho, & Choi, 2010; Lyons, Lewis, Mayrsohn, & Rowland, 2014; Middelweerd, Mollee, van der Wal, Brug, & te Velde, 2014). For instance, Lee et al. (2010) developed and evaluated an interactive smartphone application that assessed nutrition intake and exercise. The application records the daily calorie consumption for each meal, set up an exercise plan and encourages healthy eating behaviour through an implemented quiz-based learning tool. Results of users trailing the app for a period of six weeks showed a significant decrease in fat mass, weight and body mass index compared to a control group, and 58% agreement that the application was easy to use and the information provided interesting.

Overall, apps provide an ideal platform to create daily entries of behaviours, such as physical activities undertaken or healthy foods consumed from which they were then provided with weekly summaries of their reports. This not only enables to subsequently monitor and plan behaviours, but also to overcome detrimental habits and make adjustments where necessary. These apps have, furthermore, been shown beneficial and effective, largely because of the widespread and increasing use of such dynamic technology and the potential to reduce intervention delivery costs. They foster self-regulatory skills such as self-monitoring and planning, and permit a faster and more accurate assessment of ones own condition (Macdonald, Kreutz, & Mitchell, 2012).

The currently applications available in music facilitate various aspects of musical learning and preparation and are an ideal platform to target specific practice goals (e.g., tempo regulation during practice) and to encourage and increase musicians' engagement using technology as part of their every-day practice process. The smartphone applications 'pitch improver'[13] or 'Theta Music Trainer'[14], for instance, provide exercises and tasks to expand on and enhance musicians skills to recognise scales, intervals and chords, to repeat simple to complex melodies, to identify rhythms and to learn the basics of reading music. Both apps function iteratively and therefore allow the musicians to adapt to their own personal learning goals in a regulated manner.

For adequate musical preparation, the (1) the 'Music Journal Practice app to log time and beats per minute'[15]; (2) the 'Practice Center'[16] or (3) the 'Sheet Music Reader piaScore'[17] have been suggested as valuable tool to organise and monitor musicians' practice process. To put this into context, (1) allows musicians to time and monitor their practice sessions through visual feedback (graphs) and to regulate their music making by an internal metronome where musicians can set their personal tempo for each piece and view their learning progress through a beat per minute-chart. The application furthermore enables to keep musicians' repertoire organised in folders by for instance composer and instrument,

[13] https://itunes.apple.com/us/app/piano-helper/id517171792?mt=8
[14] https://itunes.apple.com/us/app/theta-music-trainer/id791698217?mt=8
[15] https://itunes.apple.com/us/app/music-journal-practice-app/id327471810?mt=8
[16] https://itunes.apple.com/us/app/practice-center/id611351544?mt=8
[17] https://itunes.apple.com/us/app/sheet-music-reader-piascore/id406141702?mt=8

to import and export the data by email and to share summary reports with others including teachers and peers; (2) offers the setting of a practice timer and a metronome tempo as well as an audio and video recorder for immediate auditory playback and visual feedback; and (3) equip musicians with the possibility to write down any notes in the score, offering a choice of pens of 3 sizes and 6 colours, as well as an easy stamp input. It also includes a virtual keyboard, a chromatic tuner, a music player (iTunes) and a voice recorder, and allows sending email with the writing down notes, making it a useful tool for both practice and teaching purposes.

The currently applications available facilitate various aspects of musical learning and preparation and are an ideal platform to target specific practice goals (e.g., tempo regulation during practice) and to encourage and increase musicians' engagement using technology as part of their every-day practice process. However, while these apps accommodate students needs to enhance specific musical skills, to sufficiently plan and time their practice sessions and to keep track on and organise their musical repertoire, they do not address or integrate the importance of meta-cognitive skills such as critical thinking and self-evaluation to reduce performance stress. To improve musicians' practice process, they should be encouraged to identify when they work most effectively, to consistently monitor their practice efficiency and to share and discuss their practice habits with like-minded. This is achieved through individualised and personalised psychological and physiological feedback where musicians are able to personally reflect on their practice progress as part of their every-day practice.

Thus, future studies are encouraged to develop a smartphone application that will primarily be guided by conservatoires and introduced to students as soon as they join the institution to ensure best chances of establishing good practice habits early on in their studies, and in order to prevent the experience of detrimental performance stress. To encourage students to use it, conservatoires might consider integrating the app as part of their curriculum, equipping young musicians with the data logged that could become part of a final assessment. Another possibility would be to use it with instrumental teachers who would incorporate the app when goal-setting with the student in the lesson, focusing for instance on the technical aspect of the students' repertoire and the overall efficiency in achieving the set targets.

Once the app has been implemented, sustaining its use should be encouraged by principle instrumental teachers who have been identified as those who first year conservatoire students rely heavily on for advice (Williamon & Thompson, 2006). Thus, integrating practice apps as part of musicians' practice routines by addressing some of the common practice behaviours associated with performance stress (Duke, Simmons, & Cash, 2009; Williamon & Thompson, 2006) seems like the ideal way to encourage and establish healthy behaviours for a successful, rewarding and sustainable career in a challenging profession.

Performance stress and optimal performance

The experience of performance stress depends on the interplay between physiological and psychological symptoms, which either have debilitating or facilitating effects on the performance quality. A seminal study which focused on the relation of physiological arousal and optimal performance, is that of Yerkes and Dodson, published first 1908 in which the so-called Yerkes-Dodson law was introduced (Yerkes & Dodson, 1908). Also known as the 'inverted-U hypothesis', the law predicts the relationship between physiological arousal and performance and suggests that too low/too high drive increases the risk of a poor performance.

The study has provided ground-breaking insight into how changes in physiology relate to performance quality, and has since then been adapted by many other researchers, such as Wilson's and Roland model of reaching optimal performance (Wilson & Roland, 2002). In doing so, they divided the causes of music performance stress into three parts; task mastery, trait and state. For instance, depending on the mastery of the task, different levels of arousal are necessary before a good performance can be achieved. Simple or gross motor activities require a high level of arousal, while fine motor tasks need relatively less arousal compared with broader tasks. Wilson and Roland (2002) furthermore refer the importance of people's personality and their environment (e.g., social support, trait anxiety, and self-efficacy) as an impact factor on performance quality (e.g., people with high level of trait anxiety should remain a low level of physiological arousal), as well as the type of situation and setting (e.g., rehearsal, performance, and audition). For instance, musicians' with high trait anxiety perform at their optimum with a well-prepared piece in a safe and low stress environment, whereas musicians with low trait anxiety need more challenging settings to reach their peak performance.

Another concept that attempted to understand the interplay between somatic and cognitive anxiety is Hardy and Parfitt's catastrophe model (Hardy & Parfitt, 1991). This model follows the basic relationship of the Yerkes-Dodson inverted-U, with the exception that performance quality—depending on the level of cognitive and somatic anxiety—suddenly, not gradually collapses after reaching a critical point. It then demands some time to recover, suggesting that a small subsequent reduction in anxiety does not really have an effect on the performance. More recently, they added another dimension to grasp the cause and experience of performance stress including the important aspect of self-confidence. To exemplify, a higher level of self-confidence automatically raises the tolerance level of physiological arousal in the presence of cognitive anxiety, resulting in a higher ability to perform the task in a successful manner (Hardy, Woodman, & Carrington, 2004).

Martens et al. (1990) also considered the multidimensionality of performance stress, yet proposed that while the relation between performance and somatic arousal are inverted-U shaped, the cognitive anxiety reveals a negative linear relationship. Additionally, they discovered that psychological and physiological symptoms may appear at different onsets. While cognitive anxiety seems to rise hours, days, or weeks before the performance event, an increased physiological arousal seem to occur and reach its peak only a few minutes before a performance (McNally, 2002).

Most recently, the relationship between emotional state and performance has been discussed by Hanoch and Vitouch (2004). Their model is based on the cue utilisation theory (Easterbrook, 1959), which, similar to the Yerkes-Dodson law, assumes emotional arousal and attentional processes to follow an inverted U-curve. Nevertheless, Hanoch and Vitouch present a more complex interpretation by emphasising the Arousal Congruent Performance (ACP). In doing so, they consider the task, the context, several types of arousal (e.g., sympathetic, attentional, etc.) as well as distinct emotions (e.g., fear, anger, etc.) to result in a specific physiological state. If, for instance, the setting, task and the emotional state during the pre-performance period is in coherence with the appropriateness of the context, the performer is said to be in the individualized zone of optimal functioning (IZOF) based on the work by Hanin (2003). Hanin tried to describe, predict, explain and control the experiences of performances by defining performance '...as a situational, multimodal, and dynamic manifestation of the total human functioning' (Hanin, 2003, p. 3), which is dependent on four interrelated dimensions: (1) the form (e.g., cognitive, behavioural, motivational); (2) the content (e.g., positive vs. negative, task relevance vs. task-irrelevance, intensity [e.g., level, range, zones]); (3) the time (e.g., topological vs. metric); and (4) context (e.g., situational, interpersonal).

While the first three are referred to subjective (meta-) experiences, the latter two represent the dynamic of these experiences. To achieve an optimal performance outcome, emotional content and intensity should be low of discrepancy and should moreover fall within the optimal zones (and outside dysfunctional ranges [in-out of the zone principle]). Furthermore, a successful performance is more likely when the emotional state is maximum enhancing and minimum inhibiting. Consequently, a poor performance is defined by highly inhibiting emotions, while an average performance leads to an equal balance of both. The relationship of emotion and performance is dynamic and bi-directional, meaning that not only emotions experiences prior to but also during a performance are determining, working on a continuous basis. In consideration of performance as a dynamic, complex, and psychophysiological intertwined system, a precise assessment of performance anxiety and consequently interventions are offered (Kamata & Tenenbaum, 2002). Future studies should therefore not only investigate the physiological alert state 5 minutes prior to the performance, but also evaluate hours and even days of musicians' performance state before an upcoming performance event, as well as use qualitative assessment tools to identify the musician's optimal state of functioning as proposed by the work of Hanin (2003).

8.5 Conclusion

It is important to understand how to measure and interpret the psychophysiological experiences of musicians accurately, prior to and during performance, as well as to offer musicians the opportunity to train and enhance their performance experience and skills in an efficient and effective manner. In this thesis, I was able to demonstrate that: (1) the pre-performance period causes the highest physical alert state; (2) the low- and high-stress performance scenarios are distinctively different in terms of physiological and psychological stress responses; (3) both standard frequency domain analysis and multiscale sample are efficient in analysing physiological data; and (4) the overall results are in agreement with the component process model proposed by Scherer (2009), which states that a higher sympathetic nervous activity is displayed in situation that involve an increased lack of control (e.g., in the pre-performance period). Particularly, during the 5-minute waiting period, musicians have experienced an increased degree of uncertainty, which is assumed to have led to the peak in physical stress response. Interestingly, the responses during the performance were often similar to those of low-stress performances, suggesting that, once the musician re-gained 'situational power', the performance has been perceived as less threatening.

In terms of the evaluation of the simulation training, the main findings show that: (1) the simulations (virtual audience and audition) have been effective tools to train and prepare performance skills; (2) physical and mental responses experienced in the simulated performance environment have been similar to those felt in real performance settings; (3) simulations have been acknowledged in terms of their key environmental features, such as stage lights, CCTV footage and the presence of a backstage manager; and (4) simulation training has been perceived as a useful tool alongside other training strategies, such as mental skills training and biofeedback.

Overall, I have paved the way for future researchers to obtain an overall understanding of the physiological responses experienced in musicians undergoing different performance contexts. I have furthermore offered future avenues to study performance stress and simulation training, using valid and reliable physiological and psychological measures as well as technologies to gather performance experiences and enhance performance skills.

Appendices

A Musicians' perceptions of using simulation training

FG 2: I was not really sure but I didn't think that I'd feel nervous. I think I just had it in my head because I knew it was just a simulator that I thought I it is not going to feel that real, I don't know why, so I was a bit unsure...I thought like it is going to be quite a big thing but in my head I always knew that it was...I thought...I will always going to know that it is going to be a simulator, but then it changes when I actually got in there...I expected it to have a less effect on me.

FG 3: Yeah the same was with me. When I...I expected it to be...like not in the room, just few walls. So...ehm...on the day of my...eh...of the simulation I have done everything like on that typical day of a performance, so I did my routine which is quite complicated so I had to wake up very early...and I...but I knew I won't be nervous at all...But I was I absolutely was...And it was hard to...ehm...to...not to concentrate on what I had in my head because I saw these...cameras...it was disturbing as well...so it was making me stressed as well.

FG 1: I thought I would still have in my head it was still a room 601 or whatever...and that it's not real but when you then get in there and you see the thing and...oh this is like an audition...it was scarier than I thought it would be.

FG 5: It was actually funny the shock of the first experience, because I noticed the huge difference in my performance and my state of mind in the two sessions. Because with the first one I didn't know what to expect and I actually felt...because you were speaking very softly...and I had that backstage feeling...and the spotlight feeling...end everything...so I didn't know what to expect so I was actually nervous...and I reflected on my performance... but... it's like an experience, so the second time I already knew what I was going to do... and I was already in the state of mind that I was ready for that... so actually if I felt nervous the first time I almost didn't feel nervous the second time because I knew what to expect so I controlled my emotions better... the setting... I don't know... that one experience helped me what I needed to do to overcome being nervous... in that specific setting.

FG 6: Yeah it was stressful because I also the fact that you are entering... and you know there is no audience but there are clapping so you don't know if you should bow... or no... and then... everything else... you don't know what to say... like thank you... you don't know... it's just... so the first time was quite... I just didn't know what was going to happen.

FG 3: With the audition panel I felt like connected... they spoke to you and I felt like I should speak back [laughter]... but he is not there so you really don't know what to do.

FG 7: And I think it is different for a singer... because I... couldn't have a pianist... and you never sing without a pianist... so that would have been an additional pressure.

How would you describe your experience using the simulation FG 9: For me I think the second one was much worse [audition panel]... cause with the performance I... it wasn't the fact that I... that it was simulated... that it was... I think for me a concert is much unless it is a quite stressful concert... just a normal... you know... normal concert... unless you are playing in a orchestra something really exposed... or highly high pressure... if you have got a solo concert I feel like I can control that better because people... people come... and they enjoy it and if they don't they don't... but in an audition the outcome is usually... that how you play usually determines something... while in concerts well if you don't like my playing... then... never mind... so it is not as stressful... so for me the second one... I felt much more nervous while the first one I didn't really feel that nervous.

FG 4: I think it was the spotlights in the first one [audience]... I don't know why I just I'd never had any thought about the lightening... it just had not crossed my mind... and then... like you said [NAME]... before you go in an like being backstage... you were sort of whispering to us... and I thought... is this actually a performance?... [laughter]... I mean you go in and it's that spotlight... and then you actually see people and it was... and after a while it was fine... and I was a bit nervous but then after a while I started to settle into it like I normally when I perform but it did actually feel like a performance because I got the nerves and I got the anxiety and then I started playing and thought... alright it's ok... I just carry on playing... but I think it was the spotlight... for me... but this of sort it made it more real... if it was just a room with computer generated people it would have felt less stressful I think, but it was definitely the lightening and the mood.

FG 8: I think if we would have stayed longer in the backstage area I would have felt more nervous. Because what happens with me is that become really nervous and when I go on stage it always goes... so because I didn't really have of that waiting around time I didn't get the chance to get nervous I think... So I mean I was... Before an audition I usually remain nervous, the nerves don't really goes way like in a concert... it usually goes when I start playing. So for me the first one [audience] it wasn't nervous at all because I didn't have a chance to get nervous when I know I usually do get nervous if you know what I mean.

FG 2: Actually the difference of setting didn't have an impact on me... I didn't actually think this one is for a concert and this one is for auditioning... I just felt... you know for me it was a performance and maybe it was my mistake that I didn't make that distinction in my head... so I could see how I would have reacted differently in terms of the situations. But practically speaking I... it didn't really make a difference for me... having a panel there or an audience... the experience was sort of the same because it is always about controlling the nerves... so... yes... [Interruption Interviewer: but for the first time you did feel more nervous than for the second one?]... yes I was definitely more nervous... and I felt... you know my hands are a bit shaky and memory slips and all that... so the performance had nothing to do what I was expecting because... I thought... oh this simulation is going to be fun and then I got there and I got nervous... and the lights... I got nervous... I think when I saw the spotlights... it was lightening that really scared me... so yeah I had a big shock the first time.

FG 4: But the second time to me I don't know... because I was playing the same piece... it was a little bit like you I kind of felt like a second shot of getting it right... once I had the experience once I knew what to expect... and I find it normally when I perform a piece anyway once you have performed it once you then know... well you need to focus on that and you need to focus on that... and that's almost what it felt like... it was a second go with it rather than... oh it is not an audience now it is an audition panel I didn't really think about that... it just felt like a second attempt... if you know what I mean.

Comparison to a real performance FG 6: Apart from the waiting around time... when you actually go in there not really... other than the fact that you would normally have an accompanist... that was a bit strange playing a piece that I was playing in a multi-class at the same time and it was bit weird playing it alone and just thinking what am I doing... but other than that no... I think the people were a bit strange because there was a person who looked completely like [NAME] [Laughter]... and I noticed that I thought oh that person look awfully like [NAME]. and then I was so focussing on that because the people weren't real but... that was complete weird.

FG 3: I think that there was a few shuffling noises almost made me feel calmer... because I don't think I was expecting noise from the audience... So I kind of expected the applause but I wasn't really expecting like that kind of real situation of a little bit of shuffling... you know like them actually moving... but that almost made me feel calmer... for some reason I don't know... it made me feel more like they are human even though they weren't... and then with the audition panel I felt connected because they speak to you when you come in and that you should speak back.... it's makes you more kind of nervous when you walk into a room and people just stare at you... and you just have to start playing. But the fact that he spoke to you first even though it was a bit awkward you didn't know what to say... thanks or... it kind of put me at ease a bit more I think... it made it feel more like a real performance because of that... which I think made me put more at ease than playing in front of computer generated people.

Improving experience FG 2: I think it is hard to do and it probably can't be done but it would be useful if the room was bigger because we are not... we don't in this little spaces... so when the room is bigger the stage is bigger and you feel exposed... you feel like you are actually performing.

FG 5: Yeah this is it as well as you were saying ... ideally for pianists it would be interesting if we could have a grand piano... because it stupid... we never have like that in an actual performance... you would have an open space and you could look at the people instead of starring at a black wall... so it is quite a difference in terms of our performance... because of the instrument we use.

FG 3: Maybe if you left people alone in the backstage area on their own... because sometimes you have to wait around a while before you go off and for me it was quite quick so... it would have good to have more time... because this makes me really nervous.

FG 9: Yeah if we going to have like 5 minutes to warm up or something... play a few notes or something... that's usually the scariest bit... if something is not going quite right and you feel oh no... like it is not... so that's when you start to think about and get more nervous I think.

FG 1: Well the backstage manager... it happen right... at least to have someone there... because usually there is always saying ok are you ready in like 5 minutes... and you think... oh yeah... right.

FG5: If maybe if you go into the backstage bit and you go in and set up like a stage manager normally does... and leave the performer for sort of a couple of minutes and then come back... and say ok everything is set up and ready... because I think that's the bit where I would get nervous is where you sort of wait and then someone goes on and starts to moving all the stands and then in your head you go: have they put the stand on the right place... have they done this have they done that... and then they come out say right you ready and you go... no... no I am not... I think that's the scary bit I think... to sort of give the impression of someone setting up the stage and then come out and say you are ready.

Possibility to use the performance simulator for what would you use it? FG 2: I think I would use it to change my maybe my performance day routine. . . like really have a routine which is every day the same. . . like what I eat and when I wake up. . . when I warm up how I warm up for everything. . . so yeah I would probably try to work on these performance conditions. . . if I could use this every day to.

Do you think anything would change in your reactions if you tried it out more often? FG 9: Yes, because if u know the place where u perform well where you feel most secure. . . if you had this routine and you perform this routine in this particular place you feel more comfortable. . . it is juts about knowing things. Knowing space knowing what's happening. . . helpful.

FG 6: I think if you used it a lot. . . eventually it would unconsciously get an idea in your head that they are not actually real and they are not reacting to what you are doing. Like the audience don't give any reaction and can't really change what you are doing. . . based on what feedback you are getting. . . and I think if I used it enough eventually it would sort of stop having an effect on me. . . it would stop being useful because you would sort of getting used to it while in areal performance you never going to have a real audience and there will always be some sort of reaction that you get from them. . . and that's different. FG 1: It is quite interesting because you talk about audience and people being in the audience and I didn't like notice any person in the audience and I didn't notice sounds from the audience. . . I mean when they talked to me [audition] I listened to it but then I didn't notice that.

FG 7: I think it would be quite good to use. . . not frequently. . . but you know when you are performing and someone mobile phone goes off or something happens that really or even distracts you or it kind of makes you think oh just something happened and I think that's why I would like to use it. If you could make the audience almost as distracting as possible so that you can carry on. . . and I don't know you probably would get used to it if you used it for a long period of time but it's like it would be a really good idea to almost put yourself in the worst possible situation so that if ever something slight happens it would not effect what you are doing...I think that's why I'd like to use it if it is possible to do that...if you think if you can sit through that you can sit through anything.

FG 8: Yeah I think that along with a piece that is a bit scary or you haven't played it for a long time that would be quite useful...something that you are quite unsure about but if you did it once you know what to expect and when it comes to the real thing you know.

FG 5: I think for the first time it would be best to be nice, but I think once you done it once it just gets you think about ok I can do that and then if it happens in a real life situation then you might not expect it...but it's fine because you might have experienced it before...it about having the mental thing even if...I don't know...having done it once just to an audience even if they are not real someone to audience that just completely distracts you...I think then if it ever happens then you would think...no I am fine I have done it before...I think that would be handy...I suppose like you said with the difficult piece I think it is quite hard...almost use it as a test to see how far it could go...because I think that would help nerves as well. I would say.

Expectations FG 1: It made me more nervous not knowing I think when I because I thought it is just a simulation it is going to be fine and I kind of took that frame in my mind and when in...but when I went in I got really nervous because it wasn't what I really expected...so I think maybe the first time it is better to have that kind of not knowing because you don't go to a performance when where you instantly how u feel...but its kind of the feeling if you have done it once then it gets you thinking of how you would use it...I think not telling us was better...for the first time.

FG 5: I would not necessarily agree because for me I...although the first time I did think it was not real I don't get as stressed as generally as with auditions...I think maybe I was a bit a nervous and I don't know whether this was because I was actually performing or just because I didn't know what was going to happen because when I perform I like to know what the venue looks like...I usually go and try and see it beforehand...so for me I can't really distinguish whether the nerves where from the performance or not really knowing of what is going to happen... so I don't really know... for the second time I can definitely say it was because of the performance because I knew what was going to happen really... but I don't really know if I was nervous because of the performance or because of the situation? Which was not... I don't want to say it was not useful because all about learning and controlling the nerves is all good practice... but it was not the same as a performance if you know what I mean... I don't know whether it was the nerves... the performance or just the situation... which is a bit of a different thing really.

FG 2: On the other hand... sometimes just before the performance something happens and u don't know what u can expect because they told u ion the last minute they had to change the instrument and you don't know the instrument at all and there is something unexpected.

FG 7: Yeah and even if you see the venue and rehearse the venue I never feel the same as when you are backstage the audience get in and you have to get in... it feels like a completely different environment to me because the whole pressure has changed... I don't know so for me not knowing was fun because I know the room how big the room was but I just didn't know how it was going to be set up... and sometimes you don't if you go into a concert.

FG 1: I think what could be helpful is to move the hour of performance... evening it is usually when you have to perform and you have thoughts about it during the day.

Use of simulation training. FG 2: It would be quite good if we could watch us back what has been recorded and if we could watch it at home... so u can notice things u wouldn't normally now and you teacher could go through after that I don't know.

FG 7: The problem is at least for me is that I felt awkward bowing whilst I am in a concert situation I don't feel awkward bowing but in that situation I felt a little unsure so I don't really know watching it back... it would be useful in some respects but I felt awkward and I then probably looked awkward but I think it depends on the person. Because if u do suffer from anxiety I think it would be a really good thing because it does feel like as if you were performing and it does get up all your nerves it sort of teaches you well it helps you to control them I suppose the more u did it... but then in some respect for me personally it would be good to have a really horrible situation where you have to do it cause u know it is not real but still provoking that feeling... but obviously watching it back would be good because I felt awkward in that situation and I didn't really feel like I was bowing to an audience I was feeling I was bowing to a wall effectively. I am not sure if it would help me with my performance how I act in stage or not.

FG 5: Actually I would not involve a teacher in the process... cause I think because it is stressful enough to go to the teacher and play so I don't think I would involve teaching In this I think I would have more of a personal experience for instance on the first occasion I played a piece that I never played in class before and I had a class on that day and I was feeling quite safe about it and then I when I felt nervous I thought o after all I was not prepared enough than I thought I was so actually that was very useful on that day because I knew what I got wrong so actually the lesson went better on that day because I had the experience in the morning. So I would definitely not involve a teacher because I think at this stage it would be good to control your emotions because you know teachers are not like when we are in high school it is much different.

FG 1: I don't agree with the teachers thing because my teachers don't really get involved when I perform if you don't tell them about the concert then they don't know about it I mean obviously you tell them but they might go over the piece a couple of times and if they remember they say good luck... But they are so busy they can't really go to a performance... they can't really be at your performances... you sort of for me I just have to get on with it and it is more the accompanist than the teacher that calms you down... we calm each other down, so I think that having an accompanist would be better for me because in big concert and audition that is the person who is going to be there.

FG 7: When you were saying when you did the audition panel the thing that actually might be quite good is the teacher as the CTA person or someone or if you are doing audition for an orchestra taking people from that orchestra that would just scares you more. That would scare me with the head of each faculty [laughter]. That would have scared me a lot more seeing him in the audience. When I practice at home I practice the piece thousands of time and a criticize myself and a I analyse everything but when I am with, my teacher I just let go of everything and anything because I know when I am wrong she will tell me.so I think that if I knew that she is somewhere and I know this is not a real performance I would feel kind of like when I am in a lesson…so maybe it is not that good. But on the other hand…maybe it is just helpful to have the recording of the performance and that show it to the teacher…but I think I would not do it…so…I think I would become too.

FG 9: If I knew my professor was watching I'd start thinking ok am I playing this in the right style, am I playing the right notes is my technique right, you know all of that would go through my head rather than o I am doing a performance…so having it as a personal experience is better because then I can actually think about the nerves the audience the performance rather than like you said like feeling in a situation where I think I have to play this right I have to do this…if that makes sense…it is a different way of looking at it as if u had a professor behind you watching.

FG 4: I think it depends on the different teaching styles on how involved they are in the performance because I have this audition coming up and I told my teacher and he so oh wow of you want you can juts play it to me beforehand but it is not we are doing this audition we have worked on this you have to do it like this more he is there to teach me what I want to learn…but if I want to perform he gives me some advice and he leads performance down to me if I want to come to him and say oh I am having problems with nerves or whatever then he will help me but he is not so actively involved he just of sorts of waits for me to come to him about performances rather than I know some teachers oh we have this master class this weekend then there are they so it depends on the teacher. Because if they are there watching your performance then it is as you were saying you think about different things and that would be useful but they are not…Individual cases.

Use of simulation training FG 6: Like if I had an audition coming up and if you can the situation and if you change the knowledge about It…as long as if u don't get too comfortable with it is can be useful all the time…as long as it's stays fresh than it's beautiful.

FG 3: If this distracting happens and if we are not aware what is going to happen I would book it before an audition.

FG 5: A technical exam... that would be my main thing as soon as I get nervous... that would be really useful... so that it completely puts u in this position and you fall apart and you.

FG 4: Safe in environment knowing that no one is there... safe space. To feel like you are in the situation but there is no consequence.

What have you learnt? FG 2: I have realised that I rely on the audience's reaction quite a lot even if people look like they are enjoying it or not you can' t know whether they are enjoying it because they are not real, so you can't really guide your performance based on how they react because there is no real reaction... i have realised that I start performance and then I glimpse off and I look at their reaction and if you see someone or a few people looking a bit.

FG 5: I thought the first trail I realised that I wasn't in a good place mentally to do the performance so it is often for me to entering the stage and then when I finished then I was I don't know what happened whether it was good or bad I don't know it just happened... but the when I did it the other week I couldn't I didn't manage to change it but I learnt that I have to work on it... And don't know how.

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