THE NEURAL IMPACT OF MINDFULNESS-BASED AND SOMATIC PRACTICES ON MUSIC PERFORMANCE ANXIETY

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Abstract

Background. Music performance anxiety and musculoskeletal disorders can lead to devastating outcomes for musicians, such as career abandonment and substance use. This thesis uses functional Magnetic Resonance Imaging (fMRI) to investigate the neurobiological mechanisms through which mindfulness-based and somatic interventions may improve musicians' health and well-being.

Studies 1 and 2 Methods. Studies 1 and 2 investigated the neural effects of a two-week-long mindfulness-based vocal improvisation program called Environmental Vocal Exploration or EVE. EVE involved vocalizing in a group setting while engaging with the body, breath, and surroundings. We also investigated the neural effects of a two-week-long traditional mindfulness program as an active control condition. Participants (N = 27) were 18–28-year-old musicians (n=10: traditional mindfulness, n=7: EVE, n=10: no intervention). Study 1 investigated pre-to-post-intervention changes in brain activity during an anxiety-provoking task and a working memory task, and Study 2 examined resting state fMRI results. Changes in state anxiety and themes from EVE discussion transcripts were also analyzed.

Studies 1 and 2 Results. Following both interventions, particularly EVE, participants' brain activity reflected increased emotional and attentional regulation. This aligned with reduced state anxiety and themes of present moment awareness that emerged. EVE's benefits may surpass those of traditional mindfulness because vocalization stimulates the vagus nerve, which helps to reduce stress.

Study 3 Methods. Among another group of 23 professional musicians, Study 3 investigated the neural effects of a somatic intervention called Body Mapping for Musicians (BMM), which took place over two formal sessions (eight hours total) and three weeks of self-guided practice. Body Mapping helps musicians correct and refine the internal representation of their body movement while playing an instrument or singing; techniques include retraining movements based on the body's anatomy and retraining attention toward both internal and external sensations. Using fMRI, we examined pre- to post-intervention changes in brain activity during the aforementioned anxiety-provoking and working memory tasks. We also examined the effects of Body Mapping on subjective anxiety, mindfulness, musculoskeletal discomfort, and working memory performance. Themes from participants' experiences with Body Mapping were also assessed.

Study 3 Results. Following the intervention, participants' brain activity reflected reduced emotional arousal during the anxiety-provoking task as well as enhanced sensorimotor integration during the working memory task. Additionally, state, trait, and performance anxiety decreased post-intervention. Themes of freedom in movement, breath, and awareness also emerged. Body Mapping for Musicians may thus reduce performance anxiety through enhanced sensorimotor processing and nonjudgmental awareness.

Conclusion. These studies provide preliminary empirical findings on how mindfulness and somatic interventions may improve musicians' health and well-being. Future studies may seek to build on this work, to further examine each intervention's effects on a larger scale.

Keywords: Mindfulness, Music Performance Anxiety, Neuroimaging, Environmental Vocal Exploration, Body Mapping for Musicians

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Contributions of Authors

For Studies 1 and 2, I, Angela K. Boland, confirm that I was responsible for conceptualization of research questions, data analysis, and writing. For Study 3, I confirm that I was responsible for the conceptualization and design of the project, study logistics, data collection, data analysis, and writing. My supervisor, Dr. Smith, was involved in all of the above processes, notably in supporting the analysis of task fMRI data. Dr. Gilles Comeau was involved in the conceptualization of the three projects. Dr. Kayla Boileau, Nicole Stanson, Dr. Nicola Oddy, and Jennifer Johnson played a role in the conceptualization and data collection for these projects. Dr. Lydia Fang played a role in resting-state functional MRI data analysis for Study 2. Laurie-Ann Welch assisted with task fMRI data analysis for Study 1, and both she and Sahil Thorul also assisted with manuscript writing, for Studies 1 and 2 respectively. Makayla Dagenais, Elena Bakker, Olivier Roy, and Nessrine Housni assisted with data collection and analysis for Study 3. All co-authors played a role in providing feedback on the manuscripts.

Table of Contents

CHAPTER ONE: General Introduction

Music Performance Anxiety

Music has a profoundly positive impact on society, though the well-being of musicians themselves remains under-researched. Both professional and student musicians commonly experience poorer mental health than the general workforce (Détári et al., 2020; Gross & Musgrave, 2020; Kegelaers et al., 2021; Vaag, et al., 2016a; Vaag, et al., 2016b) and students in other disciplines (Ginsborg et al., 2009; Panebianco-Warrens et al., 2015; Vaag et al., 2021), respectively. Musicians have also been known to face challenges to their physical health, notably playing-related injuries (e.g., due to overuse and strain of muscles and joints during practice and performance) that can be severe enough to end their careers (Bindel, 2013). A key contributor to such mental and physical health problems is music performance anxiety or MPA (Kenny, 2011; Orejudo Hernández et al., 2018).

Music Performance Anxiety refers to marked, persistent apprehension toward the socio-evaluative process of musical performance (Kenny, 2011). Performance anxiety is considered a subtype of Social Anxiety Disorder (SAD; also referred to as Social Phobia) in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5; (*Diagnostic and Statistical Manual of Mental Disorders*, 2013). Music Performance Anxiety surfaces through anxious cognitions and behaviours, as well as through autonomic arousal (Craske & Craig, 1984; Kenny, 2005) and is highly debilitating for musicians (Kenny, 2006, 2011), impacting a high proportion of musicians' personal-, professional-, and performance-related functioning (Zhukov, 2019). Fernholz and colleagues' (2019) revealed that between 16 to 59% of musicians in the studies included in their systematic review had experienced severe MPA; 60% had experienced a type of MPA at least one time during their career. Music Performance Anxiety can have devastating impacts on the lives of musicians of all ages, including prompting substance use and career abandonment (Orejudo Hernández et al., 2018).

Music Performance Anxiety can negatively impact musicians' physiological, mental, and behavioural functioning (Burin & Osório, 2016; Irie et al., 2023; Salmon, 1990; Steptoe, 2001). Mental health symptoms of MPA include high levels of anxiety, negative thoughts and feelings, and cognitive issues (e.g., memory errors; Steptoe, 2001; Viator et al., 2024; Yoshie et al., 2009). On a physiological level, heart rate, blood pressure, and perspiration increase during MPA (Moreno-Gutiérrez et al., 2023; Salmon, 1990; Steptoe, 2001; Yoshie et al., 2009). Visible changes in musicians' behaviour can also occur, including the impairment of performance quality (Burin and Osório, 2017; Kotani & Furuya, 2018; Steptoe, 2001; Yoshie et al., 2009), which may arise from feelings of anxiety and breathing-related complaints (Sokoli et al., 2022).

Although the emotional and cognitive processes underlying performance anxiety seem to overlap with those of other psychological states, such as social anxiety, post-traumatic stress disorder (PTSD), depression, obsessive compulsive disorder, and panic attacks (Mineka & Zinbarg, 2006), there are several distinctions to be made. Performance anxiety is commonly associated with SAD, both involving anxiety arising from social evaluation (Chow & Mercado, 2020; Dobos et al., 2019; Kinney et al., 2025; Koban et al., 2017). However, MPA typically occurs while playing music in front of an audience who could evaluate the performance (Brotons, 1994; Kenny, 2010; LeBlanc et al., 1997), whereas SAD commonly involves an overestimation of the degree to which the individual is being evaluated (Chow & Mercado, 2020). As noted in Kinney and colleagues' (2025) systematic review, the American Psychiatric Association (2013) specifies that one can present with performance anxiety meeting the criteria for SAD without a fear of general social settings. Evaluative apprehension due to high ego investment in their performance abilities and fear of failure is considered some of the clearest evidence of performance anxiety (Kenny, 2011).

Mechanisms of Performance Anxiety

Models of Stress Relevant to MPA

To situate our understanding of MPA, it is important to consider conceptualizations of stress and the mechanisms of stress responses. According to a transdisciplinary review of stress measurement, stress can be conceptualized as a state (e.g., chronic stress), response (e.g., acute stress), or causative agent (e.g., stressor; Epel et al., 2018; Lim et al., 2023). For the purposes of studying MPA, it is important to emphasize acute stress, considering the acute nature of the stress response in MPA.

Acute stress is marked by distinct phases of beginning (e.g., pre-performance), end (e.g., post-performance), and recovery of stress response (e.g., reduction in stress response from pre- to post-performance; Epel et al., 2018; Lim et al., 2023). There are biological, behavioural, and psychological components to acute stress (Lim et al., 2023). The biological component to stress represents distinct patterns of physiological activity within the nervous, neuroendocrine, and immune systems. The behavioural component can manifest as steps taken to mitigate the impacts of a stressor, including tendencies of moving towards or away from a stimulus (i.e., approach or avoidance). The psychological component involves affective and cognitive responses to stimuli. Affective responses alter emotional state, motivational state, and management of physiological arousal (e.g., attempting to ignore unpleasant emotions). Cognitive responses encompass appraisal, anticipation, and rumination towards stressors, either from the past or future; a key goal of such cognitions is to prepare for future stressful situations.

Appraisal is an important feature of MPA, which represents an unconscious and conscious process whereby people determine the extent to which a given stimulus exceeds their perceived coping resources (Lazarus, 1991). During primary appraisal, one can determine the relevance of a given stimulus to their personal goals, values, or beliefs, whereas in secondary appraisal, one can then evaluate whether their coping resources are sufficient for managing the demands of a stimulus (Lim et al., 2023).

According to the transactional model of stress and coping, people continuously appraise their environment's demands relative to their own coping abilities; when an environment's demands exceed one's perceived coping abilities, this leads to stress and negative emotions (Lim et al., 2023). This model suggests that the outcome of an acute stress response can be determined by appraisal (Lazarus, 1991; Lim et al., 2023). Following primary and secondary appraisals, the outcome could be perceived as either a threat, a challenge, or irrelevant (Lazarus & Folkman, 1987). When one perceives a stimulus as threatening and exceeding personal coping resources, stronger stress and negative emotional responses are elicited (Lazarus & Folkman, 1987; Lim et al., 2023). The transactional model has been applied to various fields, such as education (Fallin et al., 2012), sports performance (Hammermeister & Burton, 2001), and driving (Emo et al., 2004; Matthews et al., 2002). In MPA, this appraisal phenomenon can manifest through musicians perceiving the performance experience to be a threat that exceeds their coping resources. Such threat appraisals can be linked to problems with health, performance, and negative emotions. An appraisal of challenge is more adaptive and occurs when a given stimulus bears relevance to one's personal goals; upon an appraisal of challenge, the individual perceives that their coping resources are sufficient to meet the demands of the stimulus. Unlike threat appraisals, challenge appraisals are more commonly linked to positive health, performance, and emotional outcomes (Nicholls et al., 2012).

Anticipatory fear underlying threat bias in MPA may arise from generalisation processes, whereby past learning shapes performers' responses to novel yet similar situations (Chow and Mercado, 2020). Notably, Mineka & Zinbarg (2006) suggested that performers' detection of similarities between past and current experiences gives rise to their expected outcomes. Given this, the expectation of negative outcomes can lead to performance anxiety.

Another mechanism behind the acute stress response in MPA is cognitive dissonance, which is a discomfort arising from motivational goals conflicting with threats to self-presentation or competence (Chow & Mercado, 2020). Performing while experiencing MPA therefore requires a dissonance reduction, for example, reorienting attention away from negative feelings and/or reappraising one's feelings in a positive way (Brooks, 2014; Chow & Mercado, 2020). Consequently, the process of MPA conflicts with musicians' preparation for, choice to participate in, and commitment to a performance.

The unpleasant effects of acute stress in MPA can impact skill execution. Chow and Mercado's (2020) review noted several models that help explain this effect, including the Yerkes-Dodson's inverted U-curve (Yerkes & Dodson, 1908), Wilson's optimal plane of arousal (Wilson, 2002), catastrophe model (Hardy & Parfitt, 1991), and Individualised Zones of Optimal Functioning (IZOF; Salminen et al., 1995). Most of these models suggest that a certain level of arousal is useful and necessary for performance, though in the instance of threat appraisal, inadequately controlled emotional responses can occur, producing debilitating levels of performance anxiety (e.g., a performer experiencing what feels like a biological emergency when attempting to remain calm under pressure; Chow & Mercado, 2020; Cisler et al., 2010; Fredrikson & Gunnarsson, 1992; Steptoe, 1989, 2001). This type of response can pose significant disruptions to motor control, exacerbating the performer's concern for making mistakes (Studer et al., 2012).

Recent literature also supports the emotion schema theory (Greenberg & Paivio, 1997; Izard, 2007; Leahy, 2002), suggesting that the difference between MPA that facilitates performance and MPA that hinders performance is the emotion accompanying it. Specifically, Murphy and colleagues (2025) found that among 114 musicians who completed an online survey about their MPA experiences, positive emotion was associated with facilitating or adaptive MPA, and negative emotion was associated with debilitating MPA. This pattern may be due to positive emotion arising from a flow state; this is considered an optimally arousing state, involving creativity, concentration, and involvement in the performance, which reduces thoughts of potential failure (Csikszentmihalyi, 1975; Csikszentmihalyi & Larson, 2014; Csikszentmihalyi & LeFevre, 1989). Murphy and colleagues (2025) posit that adaptive, facilitating anxiety differs from debilitating anxiety due to the associated emotions, suggesting that, depending on level of intensity, anxiety combined with positive emotions (e.g., enjoyment, excitement) leads to a qualitatively different experience than anxiety combined with negative emotions (e.g., fear, distress; Kaleńska-Rodzaj 2020).

It is important to note that, in many cases, it is impossible to avoid all stressors when performing. Furthermore, as indicated in the models mentioned above, it can be adaptive for musicians to experience some degree of arousal during performance, since this can facilitate positive playing-related and personal outcomes. In addition, the arousal induced by competitive situations can sometimes be beneficial to mental and physical health due to it fulfilling the need of mastering new challenges (Rohleder et al., 2007). However, the crucial component is the reframing of the performance from a threat to an adaptive challenge, which aligns with one's personal and professional goals (Twitchell et al., 2025).

The Neurophysiological Underpinnings of MPA

An important neurophysiological mechanism involved in MPA is the behavioural inhibition system (BIS; Chow & Mercado, 2020). The BIS inhibits approach-related responses to stimuli perceived as threatening. Another component is the behavioural activation system (BAS), which facilitates the approach toward appetitive stimuli (McNaughton & Gray, 2000; Chow & Mercado, 2020). When the balance between the two systems is skewed toward the BIS, performance anxiety can become increasingly debilitating, thereby generating acute stress (Hagopian & Ollendick, 1994; Chow & Mercado, 2020).

In the context of acute stress, threat appraisal of an anticipated event (e.g., performance) increases the release of epinephrine, norepinephrine, and cortisol (Dienstbier, 1989; Hirsh et al., 2012; Chow & Mercado, 2020), resulting from complex interactions between the parasympathetic and sympathetic nervous systems. These physiological changes can be modulated by centrally distributed brain networks involved in emotional regulation, memory retrieval, and attentional control (Laufer et al., 2016; Mullen et al., 2012; Chow & Mercado, 2020). The activity of brain regions in the ventral affective system, involved in emotion regulation, are commonly influenced by threat bias (e.g., the ventromedial prefrontal cortex (vmPFC), orbitofrontal cortex (OFC), anterior cingulate cortex (ACC), and limbic regions (e.g., amygdala)); the dorsal affective system is also influenced by threat bias, and is responsible for emotional state appraisal (e.g., the mPFC; Britton et al., 2011; Dolcos & McCarthy, 2006).

Several studies of threat bias and anxiety have investigated neural activation patterns within the ventral and dorsal systems. In Laufer and colleagues' (2016) fMRI fear conditioning paradigm, participants with Generalized Anxiety Disorder (GAD) showed greater activation in the amygdala during the generalization of a threat from dangerous to safe stimuli. Similarly, Britton and colleagues' (2011) neuroimaging paradigm incorporated attention modulation, fear learning, as well as fear generalization principles, and found that threat appraisal led to the activation of the vmPFC, which plays a role in emotion regulation and discrimination between safety and threat. Among people with high anxiety, Kim and colleagues (2011) found less functional connectivity (i.e., negative correlations) between the vmPFC and the amygdala during resting state (i.e., lying still with closed eyes while not engaged in a cognitive task). However, among people with low anxiety, the activity between these regions was positively correlated, perhaps signaling improved regulation of anxious thoughts. Relatedly, in Zugman and colleagues' (2023) systematic review and meta-analysis on resting fMRI patterns among people with anxiety disorders, findings suggested that anxiety may be linked to resting hypoconnectivity between the amygdala and the medial frontal gyrus (mFG), ACC, and cingulate gyrus. Task-based studies have linked medial prefrontal regions to fear extinction and recall, through their connections to the basolateral amygdala (Phelps et al., 2004; Vouimba & Maroun, 2011). Cingulate regions are also involved in emotional regulation (Rolls, 2019). Hypoconnectivity between these regions among people with anxiety may thus indicate difficulty regulating fear responses (Zugman et al., 2023).

Uncertainty regarding future threat can also disrupt one's ability to avoid or mitigate the negative impact of this threat, leading to anxiety. Grupe & Nitschke (2013) found that dysfunction of the anterior insula contributed to increased anticipatory (typically negative) emotional responses. Abnormal function and connectivity of the anterior midcingulate cortex (aMCC) was also shown to play a role, preventing the identification and execution of adaptive anticipatory responses during uncertainty. Nishiyama and colleagues' (2015) fMRI study on social ostracism and support revealed similar patterns. Social exclusion (in a game-based task paradigm) was linked to heightened ACC activity, likely due to its involvement in emotional processing and regulation; emotional support was linked to increased left dorsolateral prefrontal cortex (dlPFC) activity, perhaps due to its role in orienting attention and resolving conflict. Conversely, other literature has revealed an inverse relationship between ACC activation and anxiety. For example, Blair et al. (2012) found that people with no psychopathology showed increased activity in the dorsal ACC and parietal cortices during an explicit emotion regulation task, whereas people with generalized and/or social anxiety showed no such activity. Researchers suggested that GAD and SAD may reduce one's capacity to activate emotion-regulation brain networks during explicit emotion regulation. The activation of the ACC during emotional regulation may depend on an individual's level and type of anxiety. Considering the overlap between MPA and social anxiety (*Diagnostic and Statistical Manual of Mental Disorders*, 2013), attenuated activation of emotion-regulation networks may also arise in MPA, though this has not been extensively studied.

Current Strategies for Managing MPA

Several Canadian clinical practice guidelines exist for managing social anxiety disorders, outlined in Katzman et al. (2014). In terms of pharmacological interventions, prescription of beta-blockers is common in clinical practice for performance situations (e.g., public speaking) as well as first-line antidepressants (e.g., fluvoxamine, sertraline, or venlafaxine). Talk therapy of various kinds has been successfully used as well. Notably, Cognitive Behavioural Therapy

(CBT) and exposure therapy alone are considered effective first-line treatment options for SAD. In the acute treatment of SAD, CBT and pharmacotherapy have shown similar efficacy; upon discontinuation of treatment, CBT has shown more sustained benefits than pharmacotherapy.

There are several other techniques for managing MPA that can be taught by music educators. In Mazzarolo and colleagues' (2023) PRISMA-based systematic review of nine articles, it was found that the most common music education techniques for managing MPA include simulated performance, preparation, positive outlook, and breathing techniques. Stage training can also reduce MPA symptoms, such as high heart rate, performance errors, and state anxiety (Candia et al., 2023), helping musicians become accustomed to realistic public self-exposure. Similarly, acclimatization training, goal setting, imagery, self-talk, and relaxation techniques have been utilized. Lubert et al. (2023) found that a 10-week psychological intervention encompassing these techniques reduced performing artists' fear of negative evaluation and performance anxiety; it also improved their self-efficacy and performance quality.

Online interventions have been utilized as well, involving self-directed activities for managing MPA. For instance, Moral-Bofill et al. (2022) investigated the 12-week online intervention program, "Self-Regulation Skills for Performing Musicians on flow experience" which aimed to improve musicians' levels of MPA as well as their social skills. This intervention involved six dimensions: concentration on a task, action-awareness merging, loss of self-consciousness, sense of control, transformation of time, and autotelic experience. Relative to the control group, the experimental group who took part in this intervention reported an improvement in MPA levels and flow experience from pre- to post-intervention. Interventions of this style show substantial overlap with mindfulness techniques, which warrant further investigation in the context of MPA.

Acceptance and Commitment Therapy (ACT) has also been studied as an intervention for MPA. Rather than seeking to reduce MPA, ACT seeks to enhance psychological flexibility when symptoms arise. The processes involved in ACT were shown to reduce music students' MPA levels and enhance their performance outcomes (Viator et al., 2024). Findings suggested that cognitive defusion processes (i.e., disengagement from negative, unhelpful thoughts and feelings) should be emphasized in an ACT approach for MPA treatment, before and during performances. Similarly, in Juncos and colleagues' (2017) pilot study, 12 ACT sessions led to improved performance quality, reduced shame over having MPA, increased cognitive defusion, increased acceptance of MPA symptoms, and increased psychological flexibility among student vocalists. Several outcomes of ACT overlap significantly with mindfulness practices, including present moment awareness, acceptance of experiences, and detaching from specific thoughts and feelings (Hayes et al., 2013; Juncos et al., 2017).

Despite the promising nature of several interventions for MPA, it is important to note that the prevalence of MPA has generally remained unchanged over the past 40 years. Herman & Clark, (2023) reviewed the literature on MPA treatments to better understand the limited efficacy of some current treatment options. A key finding from this review was that MPA is commonly considered to be a negative, pathological construct. Therefore, most MPA interventions seek to reduce MPA symptoms. Herman and Clark (2023) noted that de-pathologizing MPA is an important direction for the future. In line with this future direction, mindfulness-based strategies may be an important focus for MPA treatment, promoting the acceptance and awareness of MPA symptoms and the restructuring of negative cognitions and emotions. Mindfulness could, therefore, act as an empowering approach for addressing symptoms of MPA.

Mindfulness

What is Mindfulness?

Mindfulness refers to a family of emotional and attentional regulatory practices, which have been used in Buddhism and other spiritual groups for centuries, as well as in Western contexts more recently (Kabat-Zinn, 1982; Keng et al., 2011). The term 'mindfulness' became associated with Budhhism in 1881, when the Pali word 'sati' was translated into 'mindfulness' (Rhys Davids, 1881); this was not a direct translation due to how difficult the word 'sati' is to describe (Rhys Davids, 1910). Specific mindfulness practices as well as conceptions of the term 'mindfulness' differ between Buddhist traditions (Dreyfus, 2011; Sun, 2014). As is discussed in the opening of the Satipattāna Sutta, the 'Discourse on the Establishment of Mindfulness', mindfulness practice is described as a path toward the extinction of suffering and the attainment of Nirvana, involving contemplation of the four domains of the body, feelings, states of mind, and experiential phenomena (*dhamma*; Dīgha Nikāya, 22.1, as quoted in Bodhi 2011, 20; Sun, 2014).

Starting in the 1970s, applications of mindfulness arose in Western contexts. According to Kabat-Zinn (1994, 2003), mindfulness practices involve non-judgmental and purposeful attention to the present moment. Kabat-Zinn was trained by teachers of Buddhist traditions, specifically of Theravāda/Vipassanā traditions, which foster ethical purification and mental clarity (Giridharan et al., 2025). Mindfulness practices tend to share the goals of cultivating wellbeing and emotional balance (Lutz et al., 2008, 2015). Since the 2000s, research on mindfulness-based interventions for mental and physical health has increased (Schuman-Olivier et al., 2020), as these practices can enhance emotional and attentional regulation, among various other processes.

How does Mindfulness Work?

Mindfulness commonly acts by reducing mind wandering and enhancing present moment awareness. When the mind wanders (e.g., to past or imagined future scenarios), attention is disengaged from the present moment, both in terms of external surroundings and internal processes. Mind wandering is, therefore, negatively associated with nonjudgmental awareness and present-moment focus, both of which are crucial for mindfulness (Sorella et al., 2025).

On a neurobiological level, mindfulness-based interventions can alter the structure and activity of several brain regions. Treves and colleagues' (2024) systematic review revealed neural correlates of trait mindfulness by assessing 68 correlational neuroimaging studies. Task-based fMRI studies revealed that trait mindfulness was negatively associated with amygdala reactivity to emotional stimuli, indicating that trait mindfulness can promote emotion regulation. Trait mindfulness was shown in structural MRI studies to be positively associated with cortical thickness in frontal and insular cortex regions, regions that have shown respective associations with executive functioning and interoceptive awareness. Resting-state fMRI studies showed that trait mindfulness can be associated with decreased functional connectivity or FC (i.e., correlations between brain regions) within the default-mode network, indicative of reduced mind-wandering and improved attentional control; however, this is debated and depends on context.

Three key neural networks are commonly affected by mindfulness (Bremer et al., 2022): 1) the default mode network (DMN; involved in mind-wandering; Buckner et al., 2008), 2) the salience network (SN; involved in detecting relevant stimuli; Hasenkamp et al., 2012), and 3) the central executive network (CEN; involved in goal-oriented attentional engagement; Hasenkamp et al., 2012). Mindfulness meditation training has been shown to increase FC between DMN and SN regions as well as the SN and CEN regions, compared to active control conditions such as health education (e.g., Bremer et al., 2022), reflecting improved control of attention. Among people with GAD, FC of the DMN, ACC, and bilateral insula has been shown to increase following mindfulness interventions, indicating increased communication between the DMN and SN (e.g., Zhao et al., 2019). Such changes in brain networks involved in attentional and emotional regulation may represent therapeutic mechanisms for the effects of mindfulness on anxiety.

The Effects of Mindfulness Interventions on Mental Health and Well-being

In mindfulness intervention programs, state mindfulness (i.e., a temporary state of mindfulness in the present moment) is promoted, which ultimately helps develop trait mindfulness (i.e., a general tendency to be mindful). The mindfulness practices in such interventions can benefit emotional, cognitive, physical, and social well-being (Bajestani et al., 2024). Mindfulness practices have been established as evidence-based interventions for several mental health conditions, notably anxiety disorders (Wielgosz et al., 2019). Such interventions also employ versatile methods for reducing emotional reactivity and improving behavioural regulation (Keng et al., 2011), as well as improving resilience to the negative effects of stressors and boosting well-being in general (Wielgosz et al., 2019). Traditional mindfulness interventions commonly involve in-person, group practice sessions, lasting for several weeks. However, interventions lasting as little as two weeks (Berghoff et al., 2017; Vesa et al., 2016) or five days (Tang et al., 2007) have shown beneficial effects on mental health and well-being.

Mindfulness-Based Stress Reduction or MBSR courses are well-known mindfulness interventions, which have the goal of reducing stress through nonjudgmental attention to emotions, thoughts, as well as internal and external sensations (Kabat-Zinn, 2003). Activities typically include mindful breathing, movement, internal and external focus meditations, as well as group discussions about peoples' experiences with the practices.

Mindfulness-Based Stress Reduction has shown substantial benefits among individuals with anxiety disorders and related symptomatology (Vøllestad et al., 2011). Initially, Kabat-Zinn (1982) found that MBSR improved symptoms of GAD and panic disorders, showing high sustainability. Mindfulness-based interventions have shown comparable effects to CBT and pharmacological treatments for reducing symptom severity of anxiety, depression, and stress (Hofmann & Gómez, 2017; Hoge et al., 2023; Khoury et al., 2013). Mindfulness-based interventions also seem to surpass the effects of non-evidence-based treatments and active control conditions (e.g., health education, relaxation training; Hofmann & Gómez, 2017; Khoury et al., 2013; Tang et al., 2007). Additionally, Khoury and colleagues' (2015) meta-analysis revealed moderate effect sizes for studies comparing mindfulness interventions to a waitlist control condition as well as those comparing participants' outcome measures from pre- to post-intervention. These results, which were based on 209 studies including a total of 12,145 participants with various mental health disorders, were robust and demonstrated sustainability. More recently, Hue and colleagues' (2025) systematic review showed that MBSR reduced anxiety, improved emotional regulation, and improved coping skills among adolescents and young adults. Zhang and colleagues' (2025) meta-analytic findings from 32 studies (N = 1108) supported the efficacy of mindfulness training in reducing sports-related performance anxiety as well.

The primary ways in which mindfulness interventions benefit mental well-being include the reduction of trait anxiety, negative self-referential thoughts, and emotional reactivity (Goldin & Gross, 2010). Gratz & Roemer (2004) and Shapiro et al. (2006) found that reinforcement of one's values and behavioural self-regulation may also be mechanisms through which mindfulness improves one's psychological well-being. This may be because a nonjudgmental and objective presence with one's thoughts and emotions can increase the clarity of one's values and promote behaviours that are consistent with them (Keng et al., 2011). Relatedly, among individuals with high levels of self-reported mindfulness, greater engagement in valued behaviours and interests has been reported (Brown & Ryan, 2003) as well as enhanced ability to engage in goal directed behaviour even when emotionally upset (Baer et al., 2006; Keng et al., 2011). Mindfulness may, therefore, be an important method for increasing the flexibility of musicians' emotional responses during performance and improving MPA.

The Mechanisms underlying the effects of Mindfulness on Emotion Regulation in Anxiety

A process model of emotion regulation posits that emotion can be regulated during the following times in the emotion generation process: 1) selecting the situation; 2) modifying the situation; 3) deploying attention; 4) changing cognitions; and 5) modulating responses (Gross, 1998). Treves et al. (2024) emphasize two key approaches to emotional regulation, which are associated with mindfulness and are frequently discussed in neuroimaging literature. The first is reappraisal, an intentional and explicit approach (also referred to as top-down emotion regulation), where the context of an emotional response is reconsidered in order to change the response (Troy et al., 2018). Another approach to emotion regulation is reactivity, which is automatic and implicit (also referred to as bottom-up emotion regulation; Braunstein et al., 2017; Gyurak et al., 2011). In reactivity, pre-response attentional factors modulate the initial emotional response. There is a strong theoretical basis for the influence of mindfulness on attentional control and reactivity (Hölzel et al., 2011; Lutz et al., 2008). Although debated, mindfulness may also involve reappraisal when simply observing a situation or feeling instead of judging it (Hanley et al., 2021).

In Ostafin and colleagues' (2015) *Handbook of Mindfulness and Self-Regulation,* their review of existing literature showed that mindfulness can influence these explicit and implicit emotion regulation processes through the following mechanisms: 1) increased willingness to experience negative emotions due to mindfulness emphasizing nonjudgment; 2) reduced reactivity to emotional stimuli; 3) de-centering of one's perspective, improving self-esteem; 4) reduced volatility to negative emotions with practice; and finally 5) the activation or deactivation of brain areas related to emotional processing, such as the amygdala, early in the processing of an emotional stimulus.

Explicit emotion regulation (e.g., top-down reappraisal) has been suggested to involve brain regions within the CEN, such as the parietal cortex, dorsolateral prefrontal cortex (dlPFC), and ventrolateral prefrontal cortex (vlPFC), which also play a role in voluntary cognitive control and attentional processes (Guendelman et al., 2017). Implicit emotion regulation may involve the ventromedial prefrontal cortex (vmPFC) and the ventral-anterior cingulate cortex (vACC), corresponding to the processing of emotion outside of one's awareness, while simultaneously encoding stimuli in a subjective manner (Guendelman et al., 2017). Related neural models posit that the intentional control of reactivity towards external situations (as is practiced in mindfulness) is mediated by regions of the prefrontal cortex once emotional processing is occurring in limbic regions, such as the amygdala (Herwig et al., 2010; Lutz et al., 2014). The mindful practice of becoming aware of one's emotional state may thus contribute to the attenuation of emotional arousal. High trait mindfulness has also shown inverse relationships with brain activity underlying emotion regulation (e.g., right insular and prefrontal activation during the expectation of negative stimuli; Lutz et al., 2014). Therefore, people with high trait mindfulness may rely less on regulatory processes to reduce emotional arousal. Mindfulness may have a particular influence on emotion regulation in the context of anxiety disorders. Goldin & Gross' (2010) fMRI study revealed that, following an MBSR course, individuals with SAD showed reduced amygdala activity and increased activity in brain regions responsible for attentional deployment while using breath-focused attention to regulate their emotions towards negative self-beliefs. Participants' decreased levels of negative emotional experience corroborated these neural findings. Mindfulness may, therefore, enhance emotional regulation and reduce emotional reactivity among individuals with SAD, and possibly MPA. For example, following mindfulness, amygdala activation during threat appraisal (corresponding to implicit, bottom-up reactivity), may be reduced and replaced by the more explicit, regulatory process of challenge appraisal, corresponding to increased prefrontal activation.

The Mechanisms underlying the effects of Mindfulness on Attentional Control in Anxiety

Attention is considered a process of prioritizing and filtering external information, and mindfulness emphasizes the allocation of attention toward the present moment (e.g., Bishop et al., 2004). Anxiety has been shown to impair goal-directed attentional control and increase attention toward external stimuli; this includes increased attention to stimuli perceived as threatening (Eysenck et al., 2007). Impairment to the central executive functions of inhibition and shifting may underlie these effects of anxiety on attentional processing. Although anxiety does not necessarily lead to impaired performance on attentional tasks, individuals facing anxiety may use compensatory neural strategies (e.g., increasing their use of attentional processing resources). Mindfulness can counter these effects through the strengthening of attentional resources, making them more efficient.

Sustained attention and inhibition of distractors may underlie the benefits of trait mindfulness on present moment awareness and mind-wandering frequency (Chiesa et al., 2011). During mindfulness practices, processes such as mindful focus on internal breathing sensations can generalize to improved attentional control overall, even in a different sensory or situational modality (Malinowski, 2013). Specifically, meditation practice can benefit attention through improved allocation of attentional resources (Malinowski, 2013). For example, in Moore and colleagues' (2012) EEG study, meditation improved early stages of stimulus processing through more focused attentional resources (i.e., enhanced N2, a negative-going EEG waveform) and enhanced perceptual discrimination and conflict resolution (i.e., reduced P3, a positive-going EEG waveform). These attentional effects of mindfulness were further illustrated in Sumantry & Stewart's (2021) meta-analysis; the 87 studies examined focused on the impact of mindfulness meditation on attention among participants who engaged in focused attention, open monitoring, or both types of mindfulness meditation. Outcome measures included brain activity in attentional networks involved in alerting attention, orienting attention, and executive control as well as behavioural performance in various facets of executive control. Results indicated that mindful meditation improves generalized attention, alerting, executive control, inhibition, and updating.

The effects of mindfulness on attention have been further subdivided into three key attentional systems (alerting, orienting, and executive/conflict monitoring), based on Posner and Petersen's (1990) model of attention. First, alerting attention is subserved by the ventral frontoparietal network, including the right frontal and parietal cortices as well as the thalamus (Jha et al., 2007; Malinowski, 2013; Ostafin et al., 2015; Posner & Rothbart, 2007); this process can be improved through receptive attention training in mindfulness. The second and third systems, orienting attention and executive/conflict monitoring correspond to the dorsal frontoparietal network and can be improved through concentrative attention in mindfulness. Specifically, the orienting network involves regions such as the superior parietal cortex, frontal eye fields, temporal parietal junction, and superior colliculus (Malinowski, 2013). The executive network involves the dorsal ACC and various PFC regions (e.g., ventrolateral PFC; Malinowski, 2013); this network has been functionally subdivided into the aforementioned salience, default mode, and executive control networks. The attentional subsystems of altering, orienting, and executive control/conflict monitoring are also highly involved in working memory.

Working Memory, Anxiety, and how Mindfulness impacts both

Working memory and attention are interdependent processes, where working memory represents an executive function that supports and relies on attentional resources (Oberauer et al., 2019; Ostafin et al., 2015). Specifically, it represents an active process of holding information in mind, requiring sustained attention (Fougnie, 2008). Working memory was originally defined by Baddeley & Hitch (1974) as a system with limited storage and processing capabilities, which can access phonemic information, perhaps by controlling a rehearsal buffer. A more thorough characterization of working memory by Baddeley (1992) is that attentional resources are modulated by a central executive system (Marvel et al., 2019). Baddeley (1992) suggested that the central executive system oversees the following dual subsystems for holding information in mind: 1) a phonological loop for holding verbal information in mind, and 2) a visuospatial sketchpad for holding visual information in mind, each allowing the passive storage of information for 1–2 seconds. Baddeley's most recent (2010) conceptualization of working memory includes the component of an episodic buffer, a temporary store that holds multidimensional portions of information that act as a representation of the event (commonly referred to as episodes) in mind, which contain multimodal information; this buffer is thought to have a capacity of approximately four episodes.

On a neurobiological level, working memory activates frontoparietal brain regions, such as the prefrontal, cingulate, and parietal cortices. In Owen and colleagues' (2005) meta-analysis of 24 normative functional neuroimaging studies, several frontoparietal regions and a cingulate region were robustly activated during working memory; these regions included the dorsal cingulate; medial premotor cortex; lateral premotor cortex; dorsolateral and ventrolateral prefrontal cortex; medial and lateral posterior parietal cortex; and frontal poles. In a review of simultaneous EEG-fMRI correlates of working memory, similar regions were activated, including the medial prefrontal cortex, posterior cingulate cortex, posterior parietal lobe, and middle frontal gyrus (Ahmad et al., 2016). Converging neuroimaging data as well as neuropsychological data suggests that motor planning regions and secondary motor regions within the frontal lobe, cerebellum, and basal ganglia, may also be involved (e.g., the supplementary motor area (SMA; Cañas et al., 2018; Chai et al., 2018; Marvel et al., 2019). These frontoparietal, cingulate, and motor regions are differentially activated during the various stages of working memory. For example, the left dorsolateral prefrontal cortex (dlPFC) may be necessary for manipulating information in one’s working memory (Barbey et al., 2013). Motor regions, on the other hand, may generate internal motor traces that reinforce and prolong the rehearsal of information being held in mind (Marvel et al., 2019).

Among individuals with GAD or SAD, working memory impairment has been observed on both a neural and behavioural level. For example, these individuals have shown reduced dlPFC activation as well as poorer accuracy and reaction time on an N-back task (a common working memory task) than controls (Balderston et al., 2017; Chai et al., 2018). The DMN nodes of the vmPFC and ACC also showed reduced inhibition among individuals with GAD and SAD, which Balderston and colleagues, (2017) interpreted as difficulty disengaging attention from anxiety-related thoughts, leading to divided cognitive resources during working memory.

Working memory can also be impaired significantly by stressful conditions as well as negative emotional experiences (Ilkowska & Engle, 2010). For example, in Schmeichel's (2007) study, participants who were instructed to exaggerate their emotional responses to disturbing video clips showed poorer working memory capacity on a subsequent operation span task, compared to participants who were not asked to do so; those who exaggerated their responses also reported the task to be more difficult than the other group. Interestingly, emotional state did not differ between groups. Researchers concluded that while working memory performance was not affected by emotional state, increased cognitive engagement with the emotionally evocative videos impaired subsequent working memory performance. Therefore, repeated cognitive demand may impair performance of future tasks requiring attention and working memory. These findings may translate to situations where musicians show high cognitive engagement with the stressful nature of a performance (as is observed in MPA), then struggle with the attentional demands of the performance itself (Popean, 2019).

Musicians tend to outperform non-musicians on working memory (Grassi et al., 2025), but MPA can hinder working memory, leading to negative effects on performance (Popean, 2019). Working memory is important for musicians, considering that they are guided by their musical memory when playing (Meinz & Hambrick, 2010; Sloboda, 1974; Sloboda, 1978). Sloboda (1978) outlines that while playing a given part of a piece, the next part of the piece must unfold in the musician's mind before it can be played on the instrument. In the context of music practice, a kind of 'preview' is required for musicians, where they must decode visual information as they read their music, to allow a steady flow of musical output at the time of their performance. The process of obtaining a preview requires that the notes which have been seen, but not yet played, can be held in mind in preparation for when they are to be played (e.g., by looking ahead in music scores during sight-reading; Rayner & Pollatsek, 1997). High working memory capacity enhances the previewing of notes and the prediction of contexts within which subsequent notes are to be played. Such processes lend support to the idea of a tonal loop within musicians' working memory systems in addition to the phonological loop (Schulze and Koelsch, 2012). For example, Sloboda (1974) found that sight-reading skill and eye-hand span (or number of notes pianists played in a piece after the music was made invisible) were highly correlated. Working memory is also crucial for musicians' visuomotor skills (Pozenatto, 2020). Notably, musicians require an internalized visual memory for how parts of their bodies move with/on their instruments and how their posture and breathing vary depending on musical phrase. Musicians also draw from an internalized architectural structure of the piece (e.g., which parts of the piece require softer, slower, faster, or harder movements or actions). Furthermore, the central executive structure of working memory handles multi-dimensional, volitional control demands, which are strongly utilized in music training. Considering the importance of working memory for musicians, it is crucial to investigate methods of reducing MPA and optimizing this skill.

Mindfulness can have beneficial effects on working memory (Ostafin et al., 2015). Increasing empirical evidence suggests that working memory capacity is linked to mind wandering. Specifically, people with higher working memory capacity have been shown to report lower occurrence of mind wandering during attentionally demanding tasks than those with lower capacity (Kane et al., 2007). Ongoing practice of concentrative focus mindfulness-type exercises (which often require selection and maintenance of information as well as the monitoring of mind wandering) may engage and strengthen attention, working memory, and the ability to monitor mind wandering (Ostafin et al., 2015). For instance, working memory is engaged when one's attention is focused on the breath during mindfulness practices, buffering unrelated stimuli (Ostafin et al., 2015). Furthermore, mindfulness can allow retrieval of task goals when they are lost from conscious awareness; for example, the retrieval component of working memory is used when returning attention to the present moment after a period of mind wandering (Ostafin et al., 2015). As a result of such processes, mindfulness practice may, over time, improve working memory performance on high memory load tasks. Mindfulness training can elicit such improvement in at least two ways: 1) limiting reactivity to information held in working memory, thus promoting sustained attention to task-relevant information; and 2) expanding working memory capacity by allowing a larger amount of information to be held in working memory.

Several studies have revealed these beneficial effects of mindfulness on working memory, specifically that mindfulness can increase the efficiency of working memory and the size of working memory capacity (Ostafin et al., 2015). Compared to both passive control conditions (e.g., waitlist; Chambers et al., 2008) and active ones (e.g., nutrition training; Mrazek et al., 2013), mindfulness training programs have been shown to improve working memory span. Mindfulness training can also promote faster and less variable reaction times compared to control conditions (van Vugt & Jha, 2011). Mathematical modeling in van Vugt & Jha's (2011) study revealed that mindfulness training-related gains were linked to decreased disruption from irrelevant stimuli during encoding as well as higher likelihood to respond quickly.

Improved neural efficiency has been shown to underlie these enhancements in working memory (Bailey et al., 2020; Stein et al., 2022; Wang et al., 2020). The effects of mindfulness on working memory may be particularly prevalent among individuals with high levels of trait mindfulness, specifically in the domains of Attention and Awareness and Nonreactivity. Among such individuals, Stein and colleagues' (2022) fMRI findings revealed associations between Attention and Awareness scores on the Adult and Adolescent Mindfulness Scale and deactivation of the right ventrolateral prefrontal cortex (vlPFC) during the working memory condition of the N-back task (even after controlling for mindfulness experience). Nonreactivity was also associated with lower functional connectivity between the right vlPFC and right dorsomedial prefrontal cortex (dmPFC)/SMA during the working memory condition (compared to the baseline condition). Behavioural working memory performance was not correlated with any aspects of trait mindfulness. Individuals with high trait mindfulness may thus require less cognitive effort to inhibit distractors during working memory.

Taken together, the findings from the literature reviewed in this section further solidify the importance of studying mindfulness among musicians with performance anxiety. The anxiety-reducing and working memory-enhancing effects of mindfulness may jointly improve musicians' subjective and objective performance experiences, permitting reduced anticipatory anxiety and improved attentional and emotional regulation during performance.

Mindfulness as an Approach for Managing MPA

Research on the benefits of mindfulness for managing MPA is increasing. Chang and colleagues' (2003) study was among the first to investigate mindfulness as an approach for reducing MPA symptoms. Anxiety was measured via the State Anxiety Inventory (SAI). Following an 8-week meditation intervention, anxiety levels decreased among the 19 music student participants (aged 14 to 18). More recently, Czajkowski et al (2021) conducted a mixed methods study on the effects of mindfulness interventions for 25 18-38-year-old music students. Participants completed one of four 8-week MBSR/Mindfulness-based Cognitive Therapy (MBCT) courses adapted for musicians. Pre- and post-interventions, participants completed the Five Facet Mindfulness Questionnaire and a custom-made Mindfulness for Musicians questionnaire. Twenty-one of the participants also completed one-on-one semi-structured interviews following the intervention. Participants reported that the mindfulness strategies improved their MPA levels through mechanisms such as improved expressivity and changes in time perception. Mindfulness scores on both questionnaires also increased from pre- to post-intervention, and in interviews, participants reported greater awareness and focus during instrumental lessons; they also reported reduced self-criticism and increased body awareness, which improved their ability to learn their instrumental techniques. Furthermore, participants reported mindfulness practices to have enhanced their teacher/pupil communication, through the development of improved listening and improved socio-collaboration in ensemble rehearsals.

Stanson et al. (2022) examined whether a shorter mindfulness intervention of two weeks could influence MPA. This was also the first study on MPA and mindfulness to include a control group. Twenty-six young adult musicians aged 18 to 35 took part in the study, 13 of whom completed a two-week MBSR-type course and the other 13 completed no intervention. Before and after the intervention period, participants 1) completed the State component of the State-Trait Anxiety Inventory (STAI) and the Revised Kenny Music Performance Anxiety Inventory (KMPAI-R), 2) performed a piece of music in front of a mock jury panel, and 3) completed the STAI once again. This sequence of procedures permitted the investigation of pre- and post-performance anxiety levels following the stress-inducing situation of a mock audition. Following the intervention period, the mindfulness group showed reduced pre-performance state anxiety, while no such changes were observed in the control group. These findings suggest that even two weeks of mindfulness training can help reduce MPA.

There is a significant need for studies on the neural effects of mindfulness on MPA, to provide empirical, more objective evidence for its effects and to support the development of neuroscience-based mindfulness practices specifically for musicians. While there is a scarcity of literature on the neurobiological underpinnings of mindfulness interventions among musicians, Boileau et al (2024) used fMRI to investigate the neurobiology underlying a mindfulness intervention among young adult musicians with MPA aged 18-28. These participants were included in studies 1 and 2 of this thesis. In Boileau's (2024) investigation, participants either completed a two-week-long MBSR-type intervention (experimental group) or no intervention (control group). Before and after the intervention, participants completed a socio-evaluative anxiety-provoking fMRI task. During this task, brain activity increased in regions involved in attention and emotion regulation following the brief mindfulness training. These neural findings were coupled with decreases in subjective anxiety levels (measured using the STAI) from pre- to post-mindfulness training. A letter N-back task was also used to measure neural and behavioural indices of working memory. Following the mindfulness intervention, neural activity decreased in attention-related brain regions and reaction time decreased, indicating that reduced cognitive effort was required and that behavioural working memory performance was enhanced. In addition to task fMRI, neural activity was also measured during resting state fMRI. Following the intervention, functional connectivity decreased between emotion regulation brain regions, indicating more efficiency in emotional regulatory processes. Preliminary neural findings emphasized the promising nature of mindfulness as a tool for managing MPA, but further research was required.

Vocal Mindfulness-based Techniques and the Development of Environmental Vocal Exploration

It is important for musicians facing MPA to have access to diverse types of mindfulness practices, first because of individual differences in mindfulness preferences (Bajestani et al., 2024) and also because musicians may benefit particularly from mindfulness practices that emphasize movement, breath, and voice. Notably, improvisational music playing and singing combined with mindful awareness techniques have been shown to promote awareness of the performance environment as well as bonding between performers, thus reducing anxiety through enhanced creative expression (Heasman-Cossins et al., 2025; Kenny, 2011; Montello, 1989; Montello et al., 1990; Oddy, 2024). Heasman-Cossins and colleagues (2025) note that music improvisation involves several adaptive processes that can help counter the negative effects of MPA, including freedom from self-judgment, creativity and spontaneity, free emotional and musical expression, immersion in music without self-monitoring, and complete absorption in the performance.

Vocal improvisation, in particular, stimulates the vagus nerve through the act of vocalization, which helps reduce anxiety (Yuen & Sander, 2017). The vagus nerve is the 10th cranial nerve, extending widely from the medulla oblongata throughout various regions and organ systems of the body, including the pharynx, heart, and gastrointestinal system (Kenny & Bordoni, 2022; Yuen & Sander, 2017). Due to its expansive innervations ('wanderings'), this nerve plays a role in autonomic, respiratory, immune, endocrine, cardiovascular, and gastrointestinal functions (Yuen & Sander, 2017). The vagus nerve also acts as a key component of the parasympathetic nervous system, thus stimulation of this nerve has been shown to help with reduction of anxiety (Ma et al., 2025). Music Therapist, Dr. Nicola Oddy, developed an intervention entitled Environmental Vocal Exploration or EVE*,* involving vocal improvisation within outdoor and indoor spaces. A key focus of EVE is to help individuals (including performers) learn about the reciprocal relationship between the self and the places in which they are vocalizing. Dr. Oddy initially developed EVE to be a performance practice and a music therapy practice (Oddy 2022, 2024). She began using EVE in a mindfulness context as well, as it was shown to help performers improve their relationships with their instruments and environments. EVE shares foundational aspects of mindfulness training, and its effectiveness for MPA will be assessed for the first time in this thesis.

Some key mechanisms through which EVE may help reduce MPA include vocal and breath-focused practices where one directs their attention to the self (i.e., body, breath, internal sensations and feelings) and to the outer world (i.e., the environment and other people). During such practices, individuals can relinquish preconceptions of proper vocal technique to obtain a sense of freedom while vocalizing and build vocal relationships with different environments (e.g., water, tunnels, open spaces, both indoors and outdoors). For example, EVE draws from the concept of intermateriality (Eidsheim, 2015), wherein the material qualities of the place a person sings in can alter their awareness of the body, sound, and matter. EVE also cultivates gratitude for the environment and reduces fixation on one's own ruminations.

Body Mapping as a Somatic Education Technique for Musicians

Music Performance Anxiety is commonly accompanied by and can lead to physical problems while performing (Kenny, 2011; Orejudo Hernández et al., 2018), notably muscular strain during repetitive practice as well as anxiety-related bodily tension and breathing difficulties (Passarotto et al., 2023; Sokoli et al., 2022). Therefore, another important avenue to explore is the influence of body and movement awareness practices on musicians' well-being. A musician's ability to refine their physical movements has a significant impact on their musical interaction with an audience (Lee, 2018). The body is, therefore, a crucial element of music education that cannot be ignored (Lee, 2018). Statistics have shown that the majority of musicians will suffer from an injury at some point during their careers; a key contributor to such injuries is the misuse of their bodies during playing/singing (Bindel, 2013). Considering that all musicians move their bodies for a living, it is essential that they learn how to move them in a healthy way (Bindel, 2013). The effects of somatic practices incorporating movement-based techniques have yet to be examined in the context of MPA, and the neural underpinnings of these practices remain unknown.

What is Body Mapping for Musicians?

Body Mapping for musicians is an intervention designed for saving, securing, and enhancing musical careers by providing accurate information about how to move the body (Buchanan, 2005; Conable, 1998; Holt, 2016) Body Mapping draws from somatic education and mindfulness principles to provide anatomical education, movement training, and mindfulness-type practices on body, breath, and movement awareness (Buchanan, 2005; Conable, 1998).

Body Mapping for musicians was originally developed by William Conable in the early 1970s, and has been expanded further by Barbara Conable, the founder of the Association for Body Mapping Education (ABME), a growing network of Body Mapping teachers (Buchanan, 2005). Barbara Conable (1998) defines a body map as "one's self representation in one's own brain." A musician can gain access to this self-representation through observation and imagery of the self. Upon gaining such access, musicians can consciously correct and refine their body map to produce movement that is efficient, graceful, coordinated and effective. Body mapping instructors have the goal to provide music students with clear and scientifically accurate anatomical information, allowing them to address issues of muscle misuse, both during and outside of the formal course (Barrett, 2006).

According to Conable (1998), Body Mapping promotes physical freedom, allowing the musician to embody intelligence for developing musicality (Griffin, 2021). This technique can be a highly effective supplement to music students' traditional pedagogy, using simple movement, body, and breath-focused exercises for improving various aspects of performance and movement; such exercises can in turn improve performance quality and reduce MPA.

The History of Body Mapping and its Current Place in Music Curricula

The scientific term, *Body Map,* first appeared just over 100 years ago, referring to "physical self-representation" and can be otherwise known as "internal representation" (Buchanan, 2005). The conceptual definition of *Body Map* has its roots in the study of somatics.

Somatics refers to the coordination of the mind and body in movement, derived from the Greek root "soma" meaning "body" (Buchanan, 2005).

Somatic education refers to the study of the body in movement. Several kinds of somatic education are gradually being introduced into music school curricula and music festivals across North America and Europe, typically being taught by a specially trained practitioner (Lee, 2018). The original pioneers in the field of somatics were F. Matthias Alexander, Moise Feldenkrais, Mabel Todd, and Irmgard Bartenieff. Currently, neurophysiologists are studying the connections between the brain and the creation of movement, including how we map our own bodies in our brains based on the three elements of body maps: structure, function, and size (Buchanan, 2005). The element of structure represents one's human anatomy, both the musculoskeletal and nervous systems. Function refers to the physiological interactions between anatomical structures that create movement. Size represents the specific dimensions of muscles and bones.

Considering the prevalence of Body Mapping errors or mismappings (i.e., incorrect understandings of how the body works) in music curricula, there is a significant need for Body Mapping as an intervention for musicians. Based on Conable's (1998) book, *What Every Musician Needs to Know About the Body*, Licensed Body Mapping Educators teach courses for musicians to gain knowledge about how their bodies work, to address mismappings and their deleterious effects on musicians' lives. These courses incorporate the crucial element of the kinesthetic sense, which is frequently left out of music education curricula and ultimately ignored in society. William Conable, cellist, Alexander Technique teacher, and discoverer of Body Mapping highlighted the kinesthetic sense using the example that by closing one's eyes and wiggling their thumb, one does not need to touch, smell, hear, taste, or see the thumb to know how to move it: this is the essence of the kinesthetic sense, which led to the concept of Body Mapping (Barrett, 2006).

Body Mapping is one of the most recent disciplines to enter the field of somatic education for musicians (Buchanan, 2014). Body Mapping for musicians has its roots in the Alexander Technique, which draws heavily from the kinesthetic sense. The Alexander technique uses verbal and hands-on guidance to reduce musicians' self-damaging postural and movement habits, promoting adjustment of their habitual responses to stimuli (e.g., to pain and stress; Woodman & Moore, 2012). F. Matthias Alexander posits that we move according to our body map (i.e., how we think we are structured) as opposed to how we are actually structured. In the face of discrepancy between the map and one's real structure, people always move according to their body map. This discrepancy may arise from the map acting as an interface between our bodily mechanisms and conscious awareness (i.e., it is how we know ourselves; Barrett, 2006). Relatedly, the Feldenkrais Method teaches the body to move with greater efficiency and enjoyment, and reduced effort and strain (Lee, 2018).

Mismappings distort the body map, which can lead to poor performance as well as performance-related injuries, which threaten musicians' careers and reduce their well-being (Buchanan, 2005; Holt, 2016). Mismappings about the size, function, and structure of body parts are common mapping inaccuracies, as are the vagueness or absence of a body part in one's body map. Size mismapping, for example, can be seen among individuals who habitually compress their bodies owing to their self-representation of being shorter in height than in reality (Buchanan, 2005). Structural mismappings among musicians include believing that the spine stops at the bump in the back right below the shirt collar (*Body Mapping and the Alexander Technique*, 2016). Another is the belief that the spine is narrower than it is in reality (Holt, 2016). This mismapping can cause musicians to rely on their muscles as opposed to the thick stable discs in the lumbar spine to support their weight. Such misuse of muscles can hinder playing in many ways and restrict airflow. Symptoms of a mismapped spine, for example, include body stiffness, the head being pulled too far back or forward, and locked knees, all of which constitute the misuse of muscles to accommodate the mismapped spine (Holt, 2016). Functional mismappings can include incorrect posture and breathing techniques. For example, Holt (2016) identified that instructions from a variety of trumpet method books showed functional misconceptions of posture and breath, reflected by statements such as “Fill the lungs and diaphragm...grip the air by tensing the abdominal muscles.”

Body Mapping acts as a self-inquiry method of correcting these mismappings, with the premise of understanding the physiological connections within the human body that allow freedom of movement. Through understanding these phenomena, musicians can develop accurate body maps, integrate kinesthesia into sensory awareness, and develop inclusive awareness (i.e., awareness of both internal and external sensations).

Body Mapping Courses

The course, What Every Musician Needs to Know About the Body (WEM), is held by musicians certified through ABME, founded by Barbara Conable in 1997 (Barrett, 2006). Elements of Body Mapping courses that can help adjust mismappings and change one’s habitual movement patterns include examining images or models of human anatomy, drawing, and contemplating movement changes while semi-supine (i.e., lying on the back with a tilted upper body). Another component is practicing appropriate use of the body outside of Body Mapping classes, to implement habitual changes in movement using skills from the course; the self-directed aspect of Body Mapping permits self-inquiry about body maps and what beliefs musicians may wish to adjust in the process of remapping (*Body Mapping and the Alexander Technique*, 2016). Body Mapping Educator and violinist, Jennifer Johnson, advises that Body Mapping information can be most effectively imparted through hands-on guidance from a Body Mapping Educator or Alexander Technique teacher; through guided movement, students’ individual body maps can be addressed, enhancing their body awareness (Bindel, 2013).

The WEM course typically lasts six hours and is divided into six sessions (Barrett, 2006). The first hour is entitled *About Movement, Your Senses, and Attention in Playing and Singing*, which focuses the cultivation of an accurate body map, improving musicians’ sensory discernment and responsiveness, and training musicians’ attention. The second hour, called *The Core of the Body and the Places of Balance* emphasizes balance of the head atop the spine, the head and thorax atop the lumbar vertebrae, and the torso atop the legs; it also explores musicians’ balance at the knee, ankle, arch of the foot, and arm structure. The third hour, *Your Four Arm Joints and How to Use Them* introduces the four arm joints and how they are organized from the tip of the little finger to that of the shoulder blade; it also teaches musicians about gathering support for arm movement. The fourth hour, *The Movement of Breathing* emphasizes mapping breathing structures and movement during breathing; the following three conditions are taught for improving one's breathing technique: an accurate body map of the structures involved in the movement of breathing; an ongoing and lively body awareness; and freedom from tension throughout the body (Buchanan, 2014). The fifth hour, *Your Legs and How They Move as You Play* discusses the three leg joints, how the leg musculature is organized, and support for leg movement. Finally, the sixth hour is composed of individual work with instruments. In follow-up evaluations, participants in Body Mapping courses have reported improved understanding of body mechanics, through ergonomically healthier playing strategies as well as better understanding of body use in breathing, alignment, and balance (Barrett, 2006).

The course section, *About Movement, Your Senses, and Attention in Playing and Singing* highlights the concept of inclusive awareness, which may be particularly important for reducing MPA. Inclusive awareness emphasizes the completeness of sensory information and experience, which is a crucial aspect of music playing. Barbara Conable describes inclusive awareness as "the ability to be simultaneously self-perceiving and world-perceiving." T. Richard Nichols, science advisor for the Association for Body Mapping and neurophysiologist recommended using the term "attention" in describing this process, which overlaps significantly with awareness, consciousness, and mindfulness. In practice, inclusive awareness involves directing attention to a focal point (e.g., the performance) while allowing other sensations and elements of one's surroundings to enter awareness on a peripheral level, promoting an open big-picture awareness and "giving fear good company" as Barbara Conable stated. A key lesson taught to participants by Licensed Body Mapping Educators is the distinction between inclusive awareness and scanning; the former allows you to have multiple things in the periphery of your awareness (to maintain the bigger picture of awareness) but to prioritize a focal point (which could be the music/performance), based on musical/performance needs. Scanning, on the other hand, involves devoting full awareness to one thing after another. For example, the Body Mapping Educator may introduce the idea of the difference between the two being analogous to a laser beam (scanning one thing to the next, concentrating awareness on specific things) and the peripheral light that a flashlight shines on a subject, including other items than what the center of the flashlight is trained on (inclusive awareness).

Current Research on Body Mapping for Musicians

Existing research has shown that Body Mapping can exert a profound influence on various domains of musicians' lives, notably their playing, physical symptoms, and subjective performance experiences. These studies have included pianists (Bindel, 2013; Slade et al., 2020, 2023), vocalists (Buchanan, 2005), string players (Ross, 2022), wind players (Knaub, 1999), and brass players (Holt, 2016).

Recent research has revealed the promising effects of Body Mapping on physical aspects of performance and well-being, including playing-related pain, movement quality, body awareness, and performance quality (Rader, 2023, Ross, 2022; Slade, 2020). For example, Slade (2020) found that a six-hour Body Mapping course (conducted in groups of six) led to playing-related improvements among 38 18-56-year-old (M = 26.35) undergraduate and graduate piano students. Using Musical Instrument Digital Interface (MIDI) to assess performance quality (which yields data on musical pitch, velocity, and timing; Gudmundsdottir, 2010), participants showed improved right-hand articulation post-intervention. This change was not audibly perceptible by judges who listened to performances the day before and the day after the Body Mapping workshop, blind to condition; this may have been due to participants' high playing level and the short course duration. However, postural and movement changes were detectable by judges when watching silent videos of participants' performances (i.e., they could tell the difference between pre- and post-Body Mapping during the arpeggio clips), suggesting that the correction and refinement of mismappings led to improved quality of body movement.

Ross (2022) also found Body Mapping to impact movement in younger music students, specifically in terms of their subjective perceptions. Qualitative analyses were conducted on the experiences of 61 sixth grade students beginning to play strings (n = 30 who completed a 12-week Body Mapping course over a semester; n = 31 who completed traditional music instruction over a semester) using data from students' journalling about the intervention. Students who completed the Body Mapping course expressed greater awareness of how their bodies worked than students in traditional classes; they also used and retained anatomical words presented in Body Mapping lessons. Teachers found Body Mapping principles to have a positive impact on their classroom environments and student responses, and the following themes emerged: communities supporting music, classroom development, somatic awareness, and understanding of embodied experience.

Also in a classroom setting, Rader (2023) conducted a quantitative investigation of body mapping. Among 68 beginning sixth grade string students, levels of playing-related musculoskeletal disorders, interoceptive awareness, and Body Mapping knowledge were investigated pre- and post-intervention. Participants completed either a 12-week Body Mapping intervention (n = 41) or traditional pedagogy (as an active control group; n = 27). When comparing the two groups, there were significant effects of Body Mapping on the outcome measures, including improved body awareness and knowledge of Body Mapping principles. There was also a significant correlation between Body Mapping knowledge and interoceptive awareness. The active control group, however, showed an upward trend of pain and discomfort between testing points as well as reduced body awareness. These results reflected the benefits of Body Mapping pedagogy on beginner students' physical health and body awareness.

Salonen (2018) found similar improvements among university music students in an occupational health course. Participants completed 13 weekly 90-minute Body Mapping classes (n = 12). Using open coding for an Interpretive Phenomenological Analysis, themes that emerged following the courses included panorama, physical awareness, psychological awareness, and musicianship. Considerable improvement was also shown in participants' performance, postural and movement choices, as well as understanding of individual body parts and how they integrated into the whole self.

In addition to its benefits on musicians' physical well-being and performance quality, Body Mapping can lead to significant improvements in musicians' subjective perceptions of their performances. Buchanan & Hays (2014) conducted one of the first quasi-experimental studies on the topic. Twelve undergraduate music students completed a Body Mapping course throughout a university semester. Students' perceptions of their performance abilities were analyzed using thematic analysis. Researchers found that Body Mapping knowledge could positively impact these subjective perceptions, resulting from improved understanding of the connection between movement and sound. For example, most participants believed that Body Mapping enhanced their musical expressiveness, tone quality, articulation, and ability to handle faster tempi and louder dynamics. Another notable improvement was to the musicians' breath support. Musicians' understanding of technical performance elements also improved. Nine of the 12 participants (who reported some degree of success implementing Body Mapping principles to performance) felt more grounded, focused, and confident during performance after applying Body Mapping principles. Additionally, most participants reported greater ease in motion over the course of the semester, regardless of personal performance outcomes. Finally, all musicians noted an increased appreciation for the relevance and importance of Body Mapping for musicians. This study highlighted the importance of accurate biomechanical movement education in music training, to improve performance and subjective performance experiences.

A key component of Body Mapping courses designed for musicians is that they are taught by musicians themselves, who can empathize with students' experiences (Griffin, 2021). Both the teaching and learning processes of Body Mapping education were highlighted in Reyneke's (2024) qualitative study of cellists' subjective performance experiences. The goal of this study was to improve understanding of the changes and challenges that cellists experienced during a traditional WEM Body Mapping course, specifically in their musical technique, musicianship, movement, posture, pedagogy, as well as their self-maps. Semi-structured interviews were conducted among four professional cellists who were also Body Mapping educators. Using Interpretative Phenomenological Analysis, transcripts were thematically analyzed to investigate how the Body Mapping training affected participants' performance experiences. Results revealed improved subjective performance and teaching abilities among the cellists post-intervention. Body Mapping was also shown to improve kinaesthetic skills through correction of mismappings; for example, balance, posture, and movement awareness improved during performance. Following the Body Mapping course, participants noted increased feelings of artistic and physical freedom, intrinsic motivation, self-acceptance, as well as agency for change. Furthermore, musicians were able to apply fundamental Body Mapping principles to everyday life activities in addition to performance and teaching.

The need for Body Mapping Training in the Management of Music Performance Anxiety

Considering that MPA is associated with debilitating physical, mental, and performance-related problems, there is a significant need for research on the impact of Body Mapping on MPA. Passarotto and colleagues (2023) highlighted this need in their investigation of how MPA, music practice behaviours, and performance quality were related among 30 healthy pianists. Results revealed a positive correlation between state anxiety and practice time as well as number of repetitions (i.e., number of times performing the musical task). Among pianists whose playing improved, state anxiety was lower in the later part of the study. Musicians with higher anxiety may thus be at high risk for developing playing-related injuries due to overuse and repetitive strain.

In summary, Body Mapping may have important implications for reducing MPA. Notably, it promotes body awareness (Rader, 2023; Salonen, 2018) and offers an anatomical basis to movement, increasing musicians' knowledge of their bodies in movement (Buchanan & Hays, 2014; Rader, 2023; Ross, 2022). Additionally, Body Mapping increases subjective perceptions of performance quality (Buchanan & Hays, 2014; Reyneke et al., 2024). Notably, Body Mapping's emphasis on inclusive awareness is crucial for addressing MPA, as feeling self-conscious about a performance prevents the inclusion of the external world in one's awareness. This can thus be combated by including other things in one's peripheral awareness, in a soft and open manner, as opposed to scanning (or focusing one's awareness from one thing to another and succumbing to distraction). Furthermore, Body Mapping shows overlap with mindfulness techniques, which can improve MPA levels (Boileau et al., 2024; Chang et al., 2003; Czajkowski et al., 2021; Stanson et al., 2022).

The Gaps in our Knowledge of MPA, Mindfulness, Somatics, and the Brain

Although there is considerable research on MPA and on the neurobiological mechanisms of mindfulness, as well as some research on somatic pedagogy for musicians, there is a gap in our knowledge of how mindfulness and somatic interventions impact musicians' well-being, specifically on a neural level. There is also a need for mixed methods research highlighting the connections between neural and self-reported psychological effects of these practices on MPA. Considering the competitive, practice-intensive nature of music performance, it is crucial to implement evidence-based mindfulness-based techniques into music curricula and everyday practice, to improve musicians' well-being. However, many are skeptical about the use of such techniques (Van Dam et al., 2018), making it difficult to disseminate knowledge of them to musicians and to implement them in music education, practice, and performance contexts. To raise awareness of the mechanisms behind mindfulness-based techniques for musicians, there is a need to obtain empirical evidence of their effects. Specifically, to acquire a deeper understanding of the way these strategies work, the neuroscience behind the strategies warrants investigation. Such empirical evidence may, therefore, open the conversation about mindfulness techniques among musicians and inform the development, assessment, and implementation of these interventions on a large-scale.

Physiological correlates of performance anxiety have been investigated in previous literature, such as changes in heart rate, electrodermal activity, and heart rate variability (e.g., Fredrikson & Gunnarsson, 1992; Studer et al., 2012). However, research on the neural underpinnings of MPA remains scarce. Furthermore, measures of performance anxiety are primarily based on self-reported thoughts and feelings (Chow & Mercado, 2020). Despite the efficacy of self-report methods for quantifying performance anxiety levels, the accuracy of one's subjective perception of their internal state may be affected by cognitive biases (Ouimet et al., 2009; Chow & Mercado, 2020) and situational factors of performance (Smith & Smoll, 1990; Chow & Mercado, 2020). There is thus a need for more objective measures of MPA, notably, measures that employ brain imaging to reveal neural correlates of MPA.

Another gap in the literature pertains to variability of mindfulness practices. Specifically, diverse mindfulness interventions that engage various bodily functions must be explored.

Diversity in mindfulness practices is important not only because everyone responds differently to mindfulness (Bajestani et al., 2024) but also because musicians use the whole body in a performance context and may benefit most from non-traditional mindfulness and somatic interventions that incorporate movement, breath, and voice. To address this gap, EVE and Body Mapping are the two interventions to be investigated in this thesis.

It is also important to note that the evidence for mindfulness' benefits on well-being and cognition is primarily derived from cross-sectional studies. Despite their value, they allow limited conclusions to be drawn regarding mindfulness-related improvements. There is thus a strong need for repeated-measures research on the topic of diverse mindfulness practices for improving musicians' well-being, using active control conditions.

Finally, it is important to investigate accessible and cost-effective mindfulness practices, as the majority of research has investigated the effects of long-term mindfulness practice, including those of costly interventions and retreats (Bajestani et al., 2024). Brief durations of mindfulness interventions can also improve well-being (e.g., Berghoff et al., 2017; Tang et al., 2007; Vesa et al., 2016). Therefore, studying the neurobiological effects of brief, cost-effective mindfulness and somatic training may be a promising approach, to gain initial empirical findings that may stimulate further evaluation of these techniques as interventions for MPA.

The Present Studies

This thesis investigated the neural, behavioural, and subjective effects of mindfulness and somatic practices on professional and student musicians. Specifically, these three articles depict initial investigations of different kinds of mindfulness and somatic practices: a traditional MBSR-type intervention, a mindfulness-based vocal improvisation program (EVE), and a somatic Body Mapping for Musicians intervention. In the first two articles, the same group of young adult musicians underwent fMRI pre- and post-mindfulness and vocal improvisation interventions (or no intervention in the case of the passive control group). During fMRI, participants completed an anxiety-provoking task (developed by Boileau (2024)), a working memory task, and a resting-state scan. Questionnaire data on subjective state anxiety levels and MPA levels were also collected pre- and post-intervention. Study 1 also used thematic analysis to examine the content of discussion transcripts from the vocal improvisation program. The first two studies included many of the same participants and procedures as in Boileau's (2024) study. Additionally, many of the active and passive control participants for the first two studies were originally recruited from Stanson and colleagues' (2022) study investigating the effects of mindfulness on state anxiety. The third article investigated the effects of a three-week Body Mapping for musicians intervention on these same fMRI and questionnaire outcome measures among a group of professional musicians; it also included two measures of trait mindfulness and a measure of musculoskeletal discomfort. A thematic analysis was also conducted on musicians' discussions during group exploration sessions within the Body Mapping course.

Objectives and Hypotheses for the Three Articles

Study 1

Boland, A., Boileau, K., Oddy, N., Welch, L.-A., Stanson, N., Comeau, G., & Smith, A. (2025). The neural impact of a brief mindfulness and improvisational singing practice on music performance anxiety: An fMRI study. *Voices: A World Forum for Music Therapy*, *25*(1). https://doi.org/10.15845/voices.v25i1.4210

This mixed methods study had the goals to 1) investigate how two weeks of a novel mindfulness-based vocal intervention called Environmental Vocal Exploration (EVE; Oddy, 2022) could change brain activity among young adult musicians during an anxiety-provoking task and a working memory task from pre- to post-intervention, 2) examine how EVE compares to the active control condition of a traditional two-week mindfulness program and the passive control of no intervention, and 3) analyze thematic discussion data from EVE sessions in combination with findings from neural, behavioural, and psychological measures. This study was exploratory and preliminary in nature and thus had no concrete hypotheses.

Study 2

Boland, A. K., Oddy, N., Thorul, S., Boileau, K., Fang, L., Stanson, N., Comeau, G., & Smith, A. M. (2025). Preliminary rsfMRI evidence that mindfulness and improvisational singing can change the brain of musicians with performance anxiety. *International Journal of Music, Health, and Wellbeing* (IJMHW). Autumn 2025. www.musichealthandwellbeing.co.uk ISSN2515-981X. Article link: https://tinyurl.com/2vsevxd7

This resting state fMRI study had the goals to 1) investigate changes in young adult musicians' resting state functional connectivity following two weeks of EVE sessions and 2) compare the EVE group's changes in neural activity to those of an active control group who completed a 2-week traditional mindfulness intervention as well as a passive control group who completed no intervention. Due to EVE stimulating the vagus nerve through vocalization, it was hypothesized that following both the traditional mindfulness-based program and especially EVE, musicians would show increased rsFC from pre- to post-intervention between regions of the DMN, SN, and CEN, while those in the control group would show no such changes.

Study 3

Boland, A.K., Johnson, J., Stanson, N., Comeau, G., Dagenais, M., Bakker, E.G., Roy, O., Housni, N., Smith, A.M. (Under Review) The neural impact of Body Mapping Education for musicians with performance anxiety. *Scandinavian Journal of Psychology.*

Among a group of professional musicians, this mixed methods study had the goals to 1) investigate the effects of a three-week-long somatic intervention called Body Mapping for musicians (Conable, 1998) on brain activity during the aforementioned working memory and anxiety-provoking task from pre- to post-intervention, 2) examine the effects of Body Mapping on subjective anxiety levels, subjective musculoskeletal discomfort levels, subjective mindfulness levels, and working memory performance from pre- to post-intervention, 3) examine themes from participants' group exploration session discussions about their experiences with the intervention. Following the intervention, participants' brain activity was hypothesized to reflect enhanced attentional regulation, emotional regulation, motor control, and proprioceptive awareness. Participants were also hypothesized to reveal reduced anxiety, reduced physical discomfort, higher mindfulness levels, and improved working memory performance following the intervention, measured through anxiety questionnaires, mindfulness questionnaires, a musculoskeletal discomfort questionnaire, and accuracy as well as reaction time on a working memory task.

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CHAPTER TWO: The neural impact of a brief mindfulness and improvisational singing practice on music performance anxiety: an fMRI study

Boland, A., Boileau, K., Oddy, N., Welch, L.-A., Stanson, N., Comeau, G., & Smith, A. (2025). The neural impact of a brief mindfulness and improvisational singing practice on music performance anxiety: An fMRI study. *Voices: A World Forum for Music Therapy*, *25*(1). https://doi.org/10.15845/voices.v25i1.4210

Abstract

Music Performance Anxiety (MPA) negatively impacts musicians' personal lives, professional functioning, and performance quality, and is most prevalent in young adulthood. This mixed methods study investigated whether two weeks of a novel intervention called Environmental Vocal Exploration (EVE; Oddy, 2022), combining mindfulness and vocal improvisation, could alter neural activity associated with MPA in young musicians. The EVE intervention was compared with 1) a traditional two-week mindfulness program and 2) no intervention. Pre-and post-intervention, 27 musicians aged 18–28 (*n* = 7: EVE, *n* = 10: mindfulness, *n* = 10: no intervention) completed an anxiety-provoking task and a letter N-back working memory task during fMRI. A thematic analysis was also conducted on discussion transcripts from EVE sessions. During the anxiety-provoking task, blood flow in emotional processing and attention-related brain areas (e.g., limbic and salience network areas) increased from pre-to post-EVE, consistent with themes (e.g., present-moment awareness). During the post-intervention N-back, EVE participants showed less activity than the other groups in cognitive processing areas (e.g., middle cingulate gyrus), indicating enhanced neural efficiency. Both interventions may impact neural activation linked to MPA, through increased attentional and emotional regulation. Vocal improvisation in a mindfulness intervention seemed to augment such effects. Results support further study of EVE's use for MPA.

Keywords: mindfulness; music performance anxiety; neuroimaging; environmental vocal exploration; singing

Introduction

Music Performance Anxiety (MPA) refers to marked, persistent apprehension toward musical performance (Kenny, 2011) that surfaces through anxious cognitions and behaviours, as well as through autonomic arousal (Kenny, 2005). This type of anxiety is highly debilitating for musicians of various types, ages, and levels of study (Craske & Craig, 1984; Kenny, 2006; 2011), impacting a high proportion of musicians' personal, professional, and performance related functioning (Zhukov, 2019). Young adult and late adolescent musicians exhibit significantly higher MPA than older musicians (Butković et al., 2021). Therefore, it is crucial to implement accessible, cost-effective methods of alleviating MPA among young musicians.

Mindfulness, a family of emotional and attentional regulatory practices, involves purposeful, non-judgmental attention to the present moment (Kabat-Zinn, 2003). Mindfulness can enhance emotional regulation in young musicians experiencing MPA (Chang et al., 2003; Diaz, 2018). These beneficial effects may arise through improved awareness of one's internal processes (Gibson, 2019) and decreased emotional reactivity towards negative stressors (Britton et al., 2012). For example, mindfulness can increase cognitive flexibility and attentional regulation (Lutz et al., 2015), helping people appraise stimuli in a positive, adaptive way, and reduce selective attention towards negative stimuli (Malinowski, 2013). Mindfulness practices typically all share the same goals: Cultivation of well-being and emotional balance (Lutz et al., 2006). Focused attention and open monitoring are two commonly studied styles of mindfulness (Lutz et al., 2008). Focused attention involves concentration on a stimulus while ignoring irrelevant stimuli, and open monitoring involves enhanced attentional focus to all incoming sensations, emotions, and thoughts.

On a neurobiological level, mindfulness may reduce anxiety through increasing activation (i.e., cerebral blood flow) in brain regions associated with emotional regulation, such as the dorsomedial prefrontal cortex (Lutz et al., 2014). Mindfulness can also decrease activation in brain areas that produce arousal and process emotional valence (i.e., intensity), such as the right amygdala, parahippocampal gyrus, and insula (Lutz et al., 2014). Additionally, mindfulness can lead to decreased activation in areas involved in processing stress and anxiety, such as the posterior cingulate cortex (Monti et al., 2012). Networks linked to the cognitive aspects of mindfulness include the default mode network (DMN), central executive network (CEN), and salience network (SN; Lutz et al., 2015). A meta-analysis by Boccia and colleagues (2015) revealed that the positive effect of mindfulness training on emotional regulation may be due to training-related brain changes, notably increased activity in areas involved in attentional reorientation (e.g., angular gyrus) and self-regulation (e.g., anterior cingulate). Additionally, Fox and colleagues (2016) found that mindful practices were consistently associated with structural and functional changes in regions integral for emotion regulation, such as the anterior cingulate cortex (ACC).

Mindfulness practices have consistently been established as evidence-based interventions for stress, anxiety, and depression; such practices have implications for various mental health disorders due to their versatility, diversity, client/patient interest, and direct influence on resilience and well-being (Wielgosz et al., 2019). Notably, interventions lasting as little as two weeks are enough to have positive and beneficial effects (Berghoff et al., 2017; Vesa & Liedberg, 2016). However, there exist few studies on mindfulness and MPA.

Czajkowski and colleagues' (2021) study of a mindfulness intervention in the context of music performance showed that participants' mindset changes included greater awareness and concentration as well as reduced mind-wandering, distractions, self-criticism, worry, and stress, suggesting positive effects of mindfulness on MPA. Chang and colleagues (2003) also found that an eight-week meditation intervention reduced MPA levels in participants.

To understand the mechanisms through which mindfulness can influence MPA, these variables must be examined on a neurobiological level.

Environmental Vocal Exploration

There is a gap in the literature on the neurobiological influence of mindfulness techniques on MPA. The current project investigated the brain activity and anxiety levels of young adults with MPA who completed a two-week mindfulness intervention that had been adapted to include improvisational, mindful singing practice. The program is entitled Environmental Vocal Exploration (EVE; Oddy, 2022). EVE was conducted in a group setting and was led by a certified music therapist, where participants explored various environments (indoors) while doing a series of breath and vocal exercises. EVE involves directing attention inwardly (to one's own body, breath, and emotional state) and outwardly (to the environment and the people around oneself) during improvisational vocalisation experiences, with the primary goals being to improve performers' relationships with their instruments, the act of performing, and their performance environments as well as to reduce anxiety surrounding performance.

The effect of EVE on MPA has yet to be established. However, sharing all foundational aspects of mindfulness training, its effectiveness and impact are promising. EVE's inclusion of singing necessitates vagus nerve (VN) stimulation, which can reduce anxiety. Natural methods of stimulating the VN to reduce psychological stress include breathing exercises, chanting or humming, therapeutic music, mindfulness practice, and laughter (Yuen & Sander, 2017). In fact, Kalyani and colleagues (2011) demonstrated that 'OM' chanting was associated with significant bilateral deactivation in the orbitofrontal cortex, ACC, parahippocampal gyri, thalami, and hippocampi, as well as significant right amygdala deactivation, indicating reduced stress. While these natural VN stimulation methods are commonly employed in traditional mindfulness, EVE employs such methods further by incorporating singing.

The themes derived from Oddy's (2022) investigation of EVE's effects may map onto the presumed neural influences of EVE on MPA. One theme was that of listening as a practice of awareness, directing attention to the outside world, which can then direct attention away from internal anxiety. An emotional relationship between the vocal self and the environment was also highlighted, with Oddy's participants engaging playfully and creatively with the acoustic environment. Experiencing eigentones is one example (i.e., acoustical resonance or standing soundwaves), allowing participants to think beyond their ears and attend to reverberant acoustics of their environments (e.g., a tunnel).

Spirituality was another component of participants' experience during its inaugural implementation by Oddy (2022), where participants focused on the expansive nature of outer and inner worlds. Ritualistic elements were also incorporated into the practice (e.g., beginning the practice with breathing experiences and debriefing before and after singing). Similarly, community emerged as a theme, which despite some nervousness for fear of being judged, promoted belonging, connection, and gratitude for others during music-making. This was validated during the last session of the EVE mindfulness training when participants reported increased openness and engaged in spontaneous communal singing; participants' discussions of EVE seemed to amplify their connection. Several participants also experienced vulnerability when vocally improvising with others, where relinquishing preconceptions of proper vocal technique allowed a sense of freedom.

Participants' vocal relationships with different environments (e.g., rushing water, reverberant tunnel walls) varied. The effect of intermateriality (Eidsheim, 2015) was revealed, in which the material qualities of the place where people sang changed their experience of awareness to matter, sound, and their bodies. The whole concept of EVE has the effect of enhancing gratitude for the environment and reducing a fixation on singing quality. In addition, when participants paid attention to their vocal relationships with the world around them, they reflected on the environmental history of places as well as the influence of settler culture and industrialization.

The Present Study

Our goals for the present study were to 1) investigate changes in participant brain activity before and after two weeks of EVE sessions and 2) compare the neural activity of the EVE group to that of a similar group of musicians who underwent an active control condition, which was a two week mindfulness intervention (reminiscent of a mindfulness-based stress reduction program, incorporating a mix of focused attention and open monitoring styles of practices) and to another group who completed no intervention. During fMRI, participants completed an anxiety-provoking video task where they watched videos of their own and another person's musical performance, as well as a video of a judge panel critiquing the performances. This task aimed to target neural circuitry involved in MPA, permitting investigation of EVE's and mindfulness' effects on neural activation patterns during MPA. Participants also completed an fMRI letter N-back task to measure working memory (one aspect of executive functioning required by musicians), investigating differential activation of the brain's cognitive control networks before and after interventions. In addition, a thematic analysis was conducted of participants' EVE discussion transcripts to enrich our understanding of participants' feelings and thoughts during EVE. Considering that fMRI research is correlational in nature, adding a thematic component can improve our understanding of how EVE neurally influences participants' experiences of MPA.

This mixed methods study will add to the limited literature on the neurobiological effects of mindfulness and vocal practices on MPA among young musicians. The practices employed in this study are accessible, cost-effective, and may have promising impacts on well-being. Understanding the neurological effects of such training can provide initial empirical findings to evaluate the potential use of these techniques as a means to decrease MPA.

Method

Participants

Twenty-seven musicians (ages 18–28, $M = 23.1$, $SD = 2.68$) who self-identified as having MPA were included in the study. Their mean Kenny Music Performance Anxiety Inventory (KMPAI) score at the beginning of the study was 52.95; the revised KMPAI contains 40 items within eight domains of performance anxiety. Scores are expressed as percentages, with higher scores indicating more severe MPA (Kenny, 2009). Eleven participants identified as male, and 16 identified as female. The participants played a range of instruments, including piano (n = 8), violin (n = 4), percussion (n = 2), flute (n = 1), viola (n = 1), bagpipes (n = 1), clarinet (n = 1), French horn (n = 1), guitar (n = 1), trumpet (n = 1), cello (n = 1), bassoon (n = 1), double bass (n = 1), saxophone (n = 1), and vocals (n = 2). Participants' mean starting age for their instruments was 9½ years of age. There were no significant demographic differences between the three groups.

Participants were allocated to the experimental, active control, and passive control groups based on date of enrollment in the study: The first ten participants who registered were allocated to the mindfulness condition (five females and five males), the next 10 were allocated to the control condition (five females and five males), and the next seven were allocated to the EVE condition (six females and one male). Participants were recruited by posters located throughout a Canadian university's music building, through convenience sampling via email, and by contacting private music instructors. This study was approved by the Canadian university's research ethics board.

In order to participate in this study, the young adult musicians were required to have achieved grade seven from the Royal Conservatory of Music, or to have completed or currently be in the process of completing a post-secondary degree program in music. Participants were also included if they had normal or corrected vision and had normal hearing.

Participants were excluded if they had ever engaged in any kind of formal mindfulness training or if they had psychological disorders that they were currently being medicated for. They were also excluded if they had experienced loss of consciousness for more than ten minutes at any point in the past other than during surgery, if they had non-removable metal in their body or implanted devices, were currently pregnant or breastfeeding, if they had back problems, or if they were claustrophobic.

Measures

Demographic and Health Questionnaire

Demographic and health information included participants' age, sex, and previous experience with mindfulness activities (e.g., yoga, meditation, mindfulness-based stress reduction). It also included information about participants' history as musicians, such as their instrument type, number of years of music lessons, the age at which they commenced studying their instrument, and their highest degree of music training attained. Additionally, participants were asked whether they had pre-existing psychological conditions or used any substances.

Spielberger State-Trait Anxiety Inventory

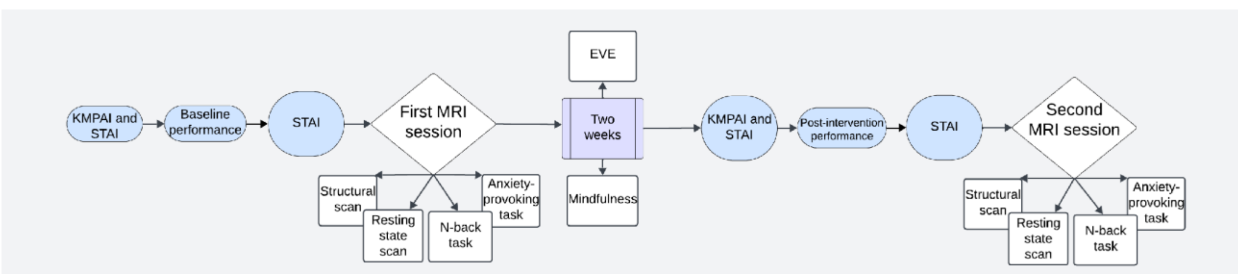
MPA was measured several times during this study using the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983), which contains two subscales: One measuring trait anxiety and the other measuring state anxiety. Only the state subscale was used in the current study. The state subscale contains 20 questions in which participants use a 4-point Likert scale to rate the extent to which a given statement resonates with how they feel in the present moment. Participants answered questions such as "I feel at ease" and "I feel strained" on a scale ranging from one (*not at all*) to four (*very much so*). A total sum score was computed after reverse scoring certain items, with higher scores indicating higher anxiety. The STAI has been employed in MPA studies (Brooker, 2018; Spahn et al., 2010) and studies on mindfulness training (La Torre et al., 2020). Previous studies have shown high content validity of the STAI. For example, it has shown correlations of 0.73 and 0.85 with the Taylor Manifest Anxiety Scale (Taylor, 1953) and Cattell and Scheier's Anxiety Scale Questionnaire respectively (Cattell & Scheier, 1963; Julian, 2011). The STAI has also shown high reliability in previous studies (Julian, 2011). For example, the STAI's test-retest reliability coefficients ranged from 0.31 to 0.86 on initial development (Spielberger et al., 1983), with intervals ranging from 1 hour to 104 days. Considering that the state anxiety scale detects transitory states, test-retest coefficients were lower for state than trait anxiety. It has also shown high internal consistency, with Cronbach's alpha coefficients ranging from 0.86 for high school students to 0.95 for military recruits (Spielberger et al., 1983).

Procedure

Participants first completed the demographic and health questionnaire and the STAI. They were then instructed to perform 6–10 minutes of solo repertoire (that they had previously performed at least once with their instrument of choice) in front of a mock panel of two judges. Participants were given 5–7 minutes to warm up with their instruments in a different room. Prior to performance, the participants were told that the jury panel would evaluate their performances. Each participant's performance was video-recorded, and this recording was used for the anxiety-provoking task during the fMRI session.

Following performances, participants completed the STAI once again. Within seven days (M = 6.7, SD = 2.3) of their initial performance session, participants underwent a one-hour MRI scan, which included a high-resolution structural scan, a resting state fMRI scan, a working memory letter N-back task, and the anxiety-provoking task (tasks described below). The data of interest for this study were the two task-based fMRI scans. (See Figure 1 for a timeline of the full study procedure.)

Figure 1. Procedural Timeline.



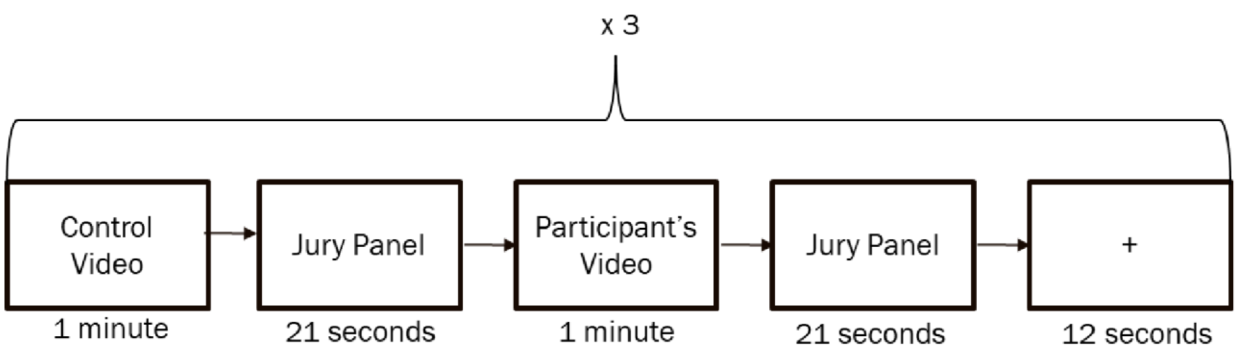
Note: This flowchart depicts a timeline of testing procedures from the beginning to the end of the study. The flow chart moves from left to right across the page: 1) Administration of the KMPAI and STAI; 2) Baseline performance; 3) Administration of the STAI; 4) Baseline MRI session which encompassed a structural, resting state, N-back task, and anxiety-provoking task scan; 5) EVE and traditional mindfulness interventions. The first four testing procedures are then repeated.

fMRI procedure

All participants underwent MRI scans at a 3.0 Tesla Siemens Biograph MR-PET scanner. Participants were asked to lie on the bed of the scanner with their head immobilized in a 12-chanel head coil. The two fMRI tasks were performed using an echo planar pulse sequence, TR/TE 3000/27 ms, flip angle 90º, FOV 24x24 cm 2, 64x64 matrix, slice thickness 3 mm, 38 axial slices, bandwidth 62.5 kHz. The results from the other pulse sequences will be presented elsewhere.

Anxiety-provoking task. Each participant's video recording of their baseline performance was used to evoke feelings of performance anxiety while in the scanner. Participants were also told that a jury panel of two individuals (a different panel of judges than those who were present at their performances) reviewed and judged the videos of their performances. The jury panel consisted of confederates. During the task, participants were shown a control video (1 minute), followed by a video of the mock jury panel writing notes about the participant's performances (21 seconds), followed by the anxiety-provoking condition (their own performance—1 minute), followed by another jury video (21 seconds). This sequence repeated three times with 12 second fixations (cross hair on screen) in between. Each video started where the last video left off (e.g., participants were shown 1 minute of a control video and the next control video they saw was a continuation of the first one-minute video and so on). This was the same for the participant videos and the jury videos as well. The control videos consisted of sections of a recording of a young adult female confederate musician playing the trumpet. All participants were shown the same jury panel and control condition confederate. The only difference between participants' imaging experience was the anxiety-provoking condition (watching themselves play their piece). Overall, this task lasted eight minutes and 42 seconds. (See Figure 2 for a visual of the task procedure.)

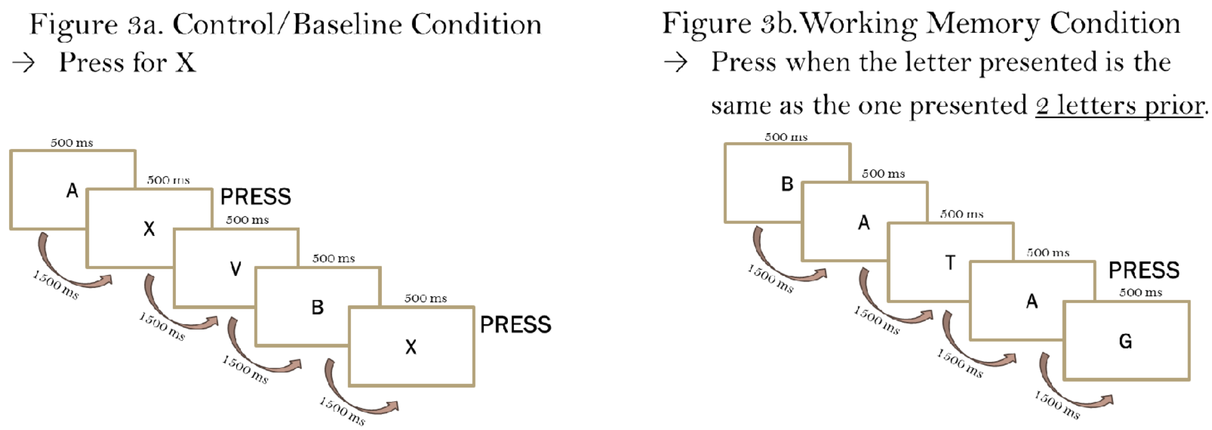
Figure 2. Anxiety Provoking fMRI Task Design.



Note: This flowchart depicts the sequence of testing procedures. Box 1 reads "Control Video" (with 1 minute underneath). Box 2: "Jury Panel" (21 seconds underneath). Box 3: "Participant's Video" (1 minute). Box 4: "Jury Panel" (21 seconds). Box 5 contains a fixation cross (12 seconds). There is a bracket above the 5 boxes with x 3 in the center.

Letter N-back task. Black letters were presented, one at a time, in the middle of a white screen. A fiber optic response pad was provided to the participants in the scanner where they were instructed to press the button with their right index finger as quickly and accurately as possible, depending on the instruction. The block design task included two conditions: 1) A control or baseline condition with Press for X presented on the screen followed by 16 stimuli (letters of the alphabet); a button press for every X presented was required, and 2) a working memory condition with Press for 2-back presented on the screen followed by 16 stimuli (letters of the alphabet except for X); the same button response was required when the letter presented was the same as the one presented two letters prior. Letters were presented for 500 milliseconds with an inter-stimulus interval of 1500 milliseconds, and blocks were counterbalanced. Six blocks of each condition were performed with six responses required within each block. Rest periods were interspersed between blocks for 21 seconds with the word 'Rest' on the screen. (See Figure 3 for a visual of the task procedure.)

Figure 3. N-back fMRI Task Design.



Note: These figures depict two conditions of the N-back task design. Figure 3a presents the control or baseline condition. Five boxes are shown overlapping, with each box down and to the right a little. In each box is a letter: A, X, V, B and X. The word "press" is written to the side of the boxes with the letter X. Figure 3b presents the working memory condition. The sequence of letters in these 5 boxes is B, A, T, A (with the word "press" to the right), G. For both Figure 3a and 3b, each box has 500ms written above and an arrow (with 1500ms written) moving from one box to the next.

The EVE and mindfulness groups then underwent two weeks of EVE and mindfulness training, respectively, while the control group was instructed not to practice any mindfulness-like activities throughout the duration of the study. Following these two weeks, all participants completed the same procedures as the pre-training session. Each participant played the same piece of music in front of the mock jury panel at both the baseline and post-training sessions. Within three days (M = 2.2, SD = 2.9) of the post-training performance session, participants completed another one-hour MRI session, which included the same imaging sequences as the first scanning session.

EVE Intervention Procedure

Ten group EVE sessions took place in three rooms of the University and were led by the certified music therapist that developed EVE. The sessions encompassed breathwork, sitting meditation exercises, exploration of the room around them, communal improvised singing, body and voice awareness exercises, and processing of experiences through discussion before and after sessions as well as through creative expression (e.g., drawing, writing).

During the first three sessions, participants lay on their mats while the music therapist invited them to direct attention to various parts of the body by first breathing toward, and then singing *into* these body parts, sending them nurturance, acceptance, and gratitude as a foundation for self-exploration. During the fourth and fifth sessions, participants engaged in both sitting and walking meditations directing attention towards the body, the room, and the outside world. They were also invited to consider (metaphorically) what they could give to and receive from the earth. During these sessions everyone improvised at the same time in a kind of "parallel play," at the same time but not together.

Sessions six through eight emphasized community. Singing experiences included the following: Participants doing their own singing while listening to others and creating joint melodies; all participants singing in a drone while one person at a time improvised over the drone; exploring sonic properties of gongs, drums, and a piano while singing along with these instruments. The ninth session emphasized reciprocity between participants' bodies and their external surroundings as well as between themselves and the other singers; this session also included a spontaneous droning experience in an improvisation circle at the end. During the last session they explored the guttural parts of their voices, focusing on the power they could foster within their bodies.

The EVE sessions all ended with activities that invited the participants to process their experiences such as mandala drawing, body scans where participants renamed and embraced feelings of anxiety that arose, drawing, writing, song writing, and further improvisational singing. There was always a group discussion afterward, when people could consider feelings that arose, and applications for the mindfulness skills learned throughout this experience.

Mindfulness Intervention Procedure

The mindfulness intervention involved a two-week training program. The program comprised ten one-hour sessions. Sessions were taught by a registered Mindfulness-Based Cognitive Therapy facilitator and were conducted in group format. Each session consisted of a variety of meditation exercises, body scanning, breath awareness, mindful walking, qigong, and discussion groups. Participants also had discussion groups focused on their daily stresses, their experiences with mindfulness training so far, and their experience with MPA in the past. Participants in this condition were asked to refrain from any additional mindfulness activities (e.g., yoga, meditation, mindfulness-based stress reduction) during this training, to reduce external variability in this group's mindfulness practices. Unfortunately, there were no transcripts obtained during this intervention as in the EVE group.

Data Analysis

Quantitative Analyses of fMRI, STAI, and N-back Performance Data

Using Statistical Parametric Mapping (SPM12), data was pre-processed from both fMRI tasks by realigning images to control for motion, normalizing the images using the Montreal Neurological Institute (MNI) brain template, and smoothing the data using a 6mm Gaussian kernel. Following pre-processing, first-level analyses were performed. For each participant, the contrast of interest for the anxiety-provoking task was the brain activity left when the control video blocks were subtracted from the anxiety-provoking video blocks. This included the first 45 seconds of each video only given the possibility of habituation of the hemodynamic response. The N-back contrast of interest was the Press for 2-back minus Press for X contrast. These contrasts were then entered into respective second-level random effects analyses to compare the pre-and post-training activation both between and within groups. Paired samples *t*-tests were subsequently used to compare each individual group's baseline versus post-training brain activity. A three-way ANOVA was performed to identify if there were any significant differences between the three groups at both time points, for each task. Given the significance found, further independent-samples *t*-tests to compare the baseline and post-training brain activity between the EVE and mindfulness, EVE and control, as well as mindfulness and control groups, were performed. Repeated-measures ANOVAs were also conducted on STAI scores and performance on the N-back task (reaction time and accuracy; i.e., number of errors), to examine within-and between-group effects. For all analyses, p-values < 0.05 were considered significant. The p-values for the fMRI analyses were Bonferroni corrected for multiple comparisons. For the STAI and N-back performance analyses, p-values were corrected using the Benjamini-Hochberg correction, with a False Discovery Rate (FDR) of 0.10, considering the exploratory nature of these analyses.

Thematic Analyses of Interview Data

Participants in the EVE group engaged in discussions before and after various practices. During these discussions, participants' responses to exercises were transcribed. A thematic analysis was conducted based on transcribed responses, using a process similar to that of Braun & Clarke (2006). First, initial notes and observations were made for all 10 sessions. Then, open codes were generated by highlighting portions of text within sessions that reflected trends across multiple participants. Finally, themes were formed based on open codes and a thematic map was generated.

Results

State Anxiety

The 3 (group) x 4 (time) ANOVA results revealed a significant main effect of time ($F(3, 22) = 6.060$, $p = 0.004$, $\eta p2 = 0.452$). Post hoc pairwise comparisons showed that time one (i.e., pre-intervention) post-performance (after participants performed their musical piece) STAI scores were significantly higher than time two (i.e., post-intervention) pre-performance (before participants performed their musical piece) STAI scores ($p < 0.001$).

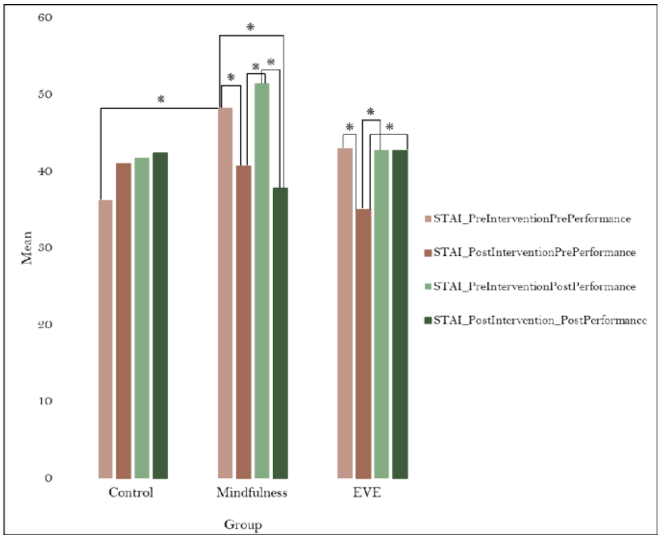
There was also a time by group interaction ($F(6, 46) = 3.464$, $p = 0.007$, $\eta p2 = 0.622$). Post hoc pairwise comparisons showed a significant difference in pre-performance anxiety scores between the no-intervention control and mindfulness groups at time one ($p = 0.023$), with mindfulness participants showing higher anxiety levels than control participants.

There was a significant difference in anxiety scores from time one to time two in the mindfulness group, where both pre-performance STAI scores ($p = 0.027$) and post-performance STAI scores ($p < 0.001$) were lower at time two. The mindfulness group also showed lower STAI scores post-performance at time two than pre-performance at time one ($p = 0.007$), as well as lower STAI scores at time two pre-performance than time one post-performance ($p < 0.001$).

Among the EVE group, time one pre-performance STAI scores were higher than time two pre-performance STAI scores ($p = 0.049$). Post-performance STAI scores were not significantly different between times one and two. Additionally, the EVE group's time two pre-performance anxiety was significantly lower than time one post-performance anxiety ($p = 0.017$)

and time two post-performance anxiety ($p = 0.011$). The control group showed no STAI differences between time points. (See Figure 4.)

Figure 4. STAI Results.



Note: This bar graph represents STAI scores. On the x-axis are three groups: control, mindfulness and EVE. Each group has four columns; light brown = pre-Intervention pre-performance; dark brown = post-intervention pre-performance; light green = pre-intervention post-performance; dark green = post-intervention post-performance. The y-axis represents participants' mean STAI scores, ranging from zero to 60. Lines with asterisks represent significant differences in several columns and this is discussed in the text above.

Thematic Analysis

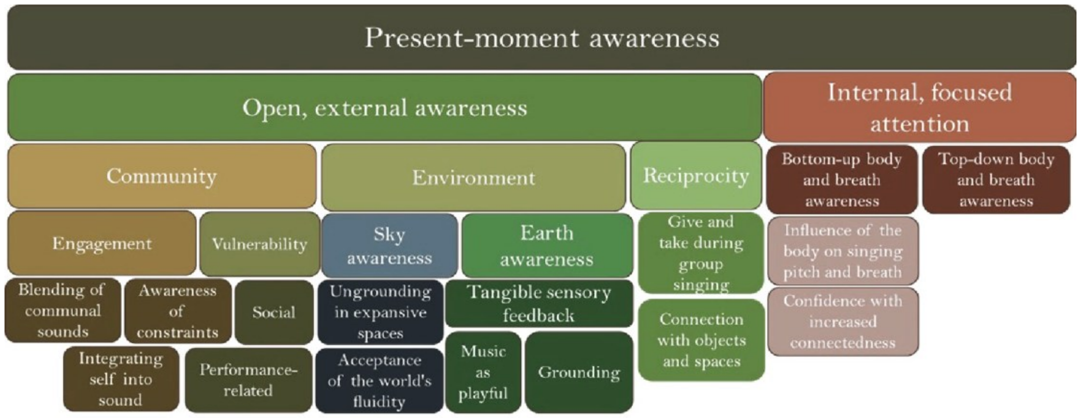
Present Moment Awareness

In both externally focused (i.e., environment and community awareness) and internally focused (i.e., breath and body awareness) aspects of EVE, several participants reported increased attention to the present moment. See Figure 5 for a thematic map. For example, in the first session, two participants' quotes revealed EVE's emphasis on *internally* focused attention on the present moment. One participant said: "[…] when I was breathing out, I tried to breathe out the past and future and focus on the present. It did help me. I was able to focus better." Another said "I found it easier to connect to my body through the breath. Started integrating the voice."

EVE also involved *externally* focused attention, as was indicated by a participant in the final session, discussing the skills they would take with them from EVE:

> Maybe I can have the centre in mind. Singing around the room. I think about the room more than what I'm doing. The people in the room. Casting your mind out rather than into the anxiety. Making music is more joyful.

Figure 5. Thematic Map.



Note: This figure represents a thematic map based on EVE discussion transcripts. All of the themes, which are discussed in-depth below, are represented as boxes in this figure. Lower boxes represent increasingly narrow subthemes, while the top boxes represent dominant ones.

Open, External Awareness

Community. This subtheme within "Open, External Awareness" represents participants' statements about both comfortable and uncomfortable forms of engagement with other participants during singing practices, such as during sessions six and seven.

Engagement: "Engagement" was revealed in three ways: First, it was revealed through "Blending of Communal Sounds." For example, in relation to both drawing and singing exercises in EVE, a participant said: "I was thinking about homogeneity and blending, but also the way I drew it I started all around the edge. We started far away from each other and slowly came together. We blended so that we didn't stand out."

A second subtheme of engagement was "Awareness of Constraints," a potential hindrance to full engagement with EVE that was noted by a few participants. This subtheme was discussed when describing pictures that they drew based on feelings evoked from communal singing exercises:

> I was thinking—we try to make it an organic thing, interacting with each other in a spur of the moment way, but at the same time we're still bound by the hour here. We can't take our time completely. We can't do an expansive thing and that really sucks. We're on this schedule and all have other things to do today, and we can't let things be as they are. Then I was thinking that everything in nature has constraints on it. Plants are limited by how much sunlight they have, how much ground space, but that doesn't mean it's not real. [I describe a part of the picture I see: That little plant is surrounded by warmth and somehow contained]. It's representative of memory to me.

Finally, engagement was shown through "Integrating Self into Sound" when singing as a group, as was expressed by one participant: Usually, I'm so in my head and it was hard to focus on what was outside of me. Trying to integrate myself into the sound. I started off caring what I sound like and then do just whatever. It was fun.

Vulnerability: Another aspect of "Community" is "Vulnerability" a subtheme that emerged in contexts of both "Social" and "Performance-Related" vulnerability. Social vulnerability was exemplified by two participants during a walking exercise, involving greeting other participants with one's voice. First, a participant said: "Because I'd done it before I was a little more comfortable. But my social tendencies were coming out. I was thinking that people were running away from me as I was heading toward someone."

Vulnerability evoked by performance-related vulnerability was also shown by participants discussing how their greetings to one another felt like a performance, as was seen in the following participant quote:

> The transition between being a person who's talking to others and then transitioning to performer of music. I find it hard and awkward. If I introduce myself and then start singing, I have to transition between my normal speaking voice and my singing voice, getting ready or getting into character, or getting into the vibe of the piece.

Environment. This is a subtheme within "Open, External Awareness" representing participants' statements about their connections to the spaces they were in and the objects surrounding them. Statements about the environment encompassed awareness of both the sky and earth, thus we added the subthemes of "Sky Awareness" and "Earth Awareness."

***Sky Awareness**:* "Sky Awareness" contained two subthemes: "Ungrounding in Expansive Spaces" and "Acceptance of the World's Fluidity." "Ungrounding in Expansive Spaces" was exemplified during session 8 and 9. In session 8, various participant quotes revealed a sense of awe, or vastness in a large space, that, contrary to grounding experiences, made participants feel more of a sense of oneness with the universe (i.e., blurred lines between where the individual ends and where the rest of the world begins). Such oneness evoked a mixture of feelings for participants, as is exemplified in the following quotes about singing in spaces. An example of such a quote was: "Singing out into the universe ungrounds me. I'm a quiet person and I play quietly."

Another example was: "This was one of the harder ones for me. How big of a space that was to fill." Another participant said: "It feels more connected. I closed my eyes a lot. I felt like beyond the outside world, I could go further in perceiving what's around. You don't feel so isolated."

"Acceptance of the World's Fluidity" was revealed during session 9. Participants discussed several aspects of the fluid nature of the world. A participant had arranged her page so that it was in the shape of a diamond and said the following quote:

> At first, I was wondering about the orientation. The word didn't come to me at first, but I had the feeling from the experience and looking out. I was trying to be open minded and feel based on what I just saw. Yesterday the sky was blue and today it's grey, so I didn't want to have preconceptions. I tried to think with a wider spectrum of things. It was a feeling of freeing. Everything is up and down as [name of another participant] said,

> between the good and the bad. In the end the word that came to me was "fluid." I didn't have any shapes that came to mind—just colours.

Earth Awareness*:* "Earth Awareness" encompassed three additional subthemes: "Grounding," "Music as Playful," and "Tangible Sensory Feedback." The subthemes within "Earth Awareness" were revealed across sessions, primarily during sessions four and five. In these sessions, participants sang together in a circle, then moved around the room while vocalizing and focusing on outdoors. First, the theme of "Tangible Sensory Feedback" emerged, based on participants' statements about the significance of their sensory experiences in the room while singing, increasing their connections to the outside world. One comment that exemplified this was: "Touching surfaces. This one makes sound—that one doesn't make sound." Similar sentiments were: "The corners were great. And the alcove," Two related participant comments included:

> With touching stuff, I felt the lower notes. Paper, plastic, and wood were higher. I was trying to separate—knowing where the materials came from what I just perceive—the pitch of stuff. Anything wooden inspired higher notes. If I touched metal, my tone was lower. The pitch was different according to different objects. Letting the material flow through and bounce off of me. I also felt exhausted afterward too. I felt more comfortable reconnecting with basic materials that we always see, but then taking time to identify them and connect with them. This room doesn't feel scary.

> It's a good way of thinking. If I saw this room as a performance venue it would make sense to get comfortable with the materials in the room beforehand. Especially for piano where you don't necessarily know the instrument beforehand. Spend time with the instrument. Humanize it.

Second, the subtheme of "Music as Playful" emerged, where participants made statements about the fun in exploring the environment and community with their voices. One participant said: "I definitely felt more comfortable than yesterday. I'm more open to being more playful." Another said "Casting your mind out rather than into the anxiety. Making music is more joyful."

Third, "Grounding" was shown in participants' quotes while singing and moving around the room. One participant said "I ended up singing by that pillar there. It probably has a connection to the ground."

Reciprocity. "Reciprocity between the Self and the Outside World" is a subtheme within "Open, External Awareness" representing participants' statements about feelings of taking in and giving out to the environment and the community (i.e., an exchange of focus, care, nurturance, breath, and sound). Within the "Reciprocity" are the subthemes of "Give and Take during Group Singing" and "Connection with Objects and Spaces."

Give and Take during Group Singing*:* "Give and Take during Group Singing" was exemplified through several participant quotes about the exchange between themselves and other participants. One said: "It was give and take. I was more harmonizing with people or being an echo. It really enriches a piece and makes it great but it's not the focus." Taking a more analytic standpoint, another participant said: "I didn't realize that people were supposed to make harmony. I started analysing. If she's singing an A then I should sing an F."

Connection with Objects and Spaces*:* "Connection with Objects and Spaces" was shown through participants' energetic reactions to their surroundings while singing. For example, one participant quote was:

> I was thinking about resonance and cooperation. A certain tone would resonate really well. I feel like even though it was just my sound that was resonating it felt like a lot more than just me. I feel like that's how I want to feel in general as I move through the world. I want to feel like I'm putting something in and getting a lot back. It's not as if I'm taking from anyone else, but just positioning and what I'm doing and where I am at the time. My efforts are able to be multiplied, I guess. That sense of reciprocity. I loved looking out the window. I would stand there all day and just watch the world go by. It was very comforting to know that the world goes on with or without me. It helps me know that I can find my place within it.

Internal, Focused Attention

Bottom-up Breath and Body Focus. This subtheme within "Internal Focused Attention" comprised of statements about how participants would develop thoughts and feelings about their bodies and vocal tones based on bodily feedback. Participants tended to express these feelings in session 3, after achieving more top-down integration of the voice and breath into the body. There were two additional subthemes within this one: "Influence of the Body on Singing Pitch and Breath" and "Confidence with Increased Connectedness."

Influence of the Body on Singing Pitch and Breath. Participants discussed how scanning different parts of the body influenced their vocal output. One of these statements was: "Yesterday, I was singing a high note, and today I noticed that I was going toward my low register. I found that easier to feel in my body." Another was: "It feels like it vibrates more, and it was a good way to connect. The head voice and the chest voice."

Confidence with Increased Connectedness. This was another subtheme exemplified in participants' descriptions of the connections they felt to their bodies during vocal and breathing exercises, emphasizing that body parts of greater strength are where their musical confidence was strongest. One participant said:

> I think that confidence is physical strength. I have that association in my mind. If my core is strong, then I can't be physically overpowered. That's where my brain was. There were times when I was stronger than I am now, and I felt more confident in general. More centred.

Another participant said: "At first, I thought it was in my feet, but then my stomach and then my upper body. I use my upper body more." Finally, another quote was: "From today I can take my sense of confidence. Maybe I can have the centre in mind."

Top-down Breath and Body Awareness. This is a subtheme within “Internal Focused Attention,” comprised of statements about how participants’ thought patterns as well as their breath and vocal patterns influenced their body sensations. This subtheme was shown through quotes about the connections between the voice, breath, and body, and how it became easier to connect them under specific circumstances. One participant said: “I found it easier to connect to my body through the breath. Started integrating the voice. I find myself more at ease than I expected not knowing what to expect.” Another said “I found it I was more connected on the lower notes.” Another participant said: “I liked seeing how it was so hard to focus on just breathing. I feel like that can help me focus on other stuff, since breathing is so basic. It might help me focus in general.” Finally, another said: “When I’m performing, I’m all in my head and I’m trying to get more in my body and become present and aware, and I’m hoping that this will help me get to that.”

Anxiety-Provoking Task

Participants also showed quantitative changes in brain activity, between time points and between groups. Paired samples *t*-tests showed several changes in brain activity within the EVE and mindfulness groups from pre-to post-intervention. First, during the Anxiety Provoking task, participants in the EVE group showed increased activity from baseline to post-intervention when watching themselves compared to another in the right superior temporal gyrus, right anterior cerebellum, middle cingulate, right postcentral gyrus, right middle temporal gyrus, and right fusiform (Table 1). The mindfulness group showed an increase in activity post-intervention compared to pre-intervention in the hippocampus, caudate, right fusiform gyrus, right lingual gyrus, left inferior temporal gyrus, right supplementary motor area (SMA), left paracentral lobule, and left precentral gyrus (Table 1).

The three-way ANOVA revealed a significant interaction effect between group and time. Comparing the EVE and mindfulness groups post-intervention using follow-up independent samples *t*-tests, the EVE group showed more activity in the caudate, right parahippocampal gyrus, right middle temporal gyrus, left thalamus, inferior orbitofrontal gyrus**,** and right temporal pole than the mindfulness group (Table 1, Figure 6). The EVE group showed more activity in similar regions compared to the no-intervention control group, including bilateral parahippocampal gyrus, caudate, bilateral thalamus, middle and superior temporal gyri, left temporal pole, and right insula (Table 1).

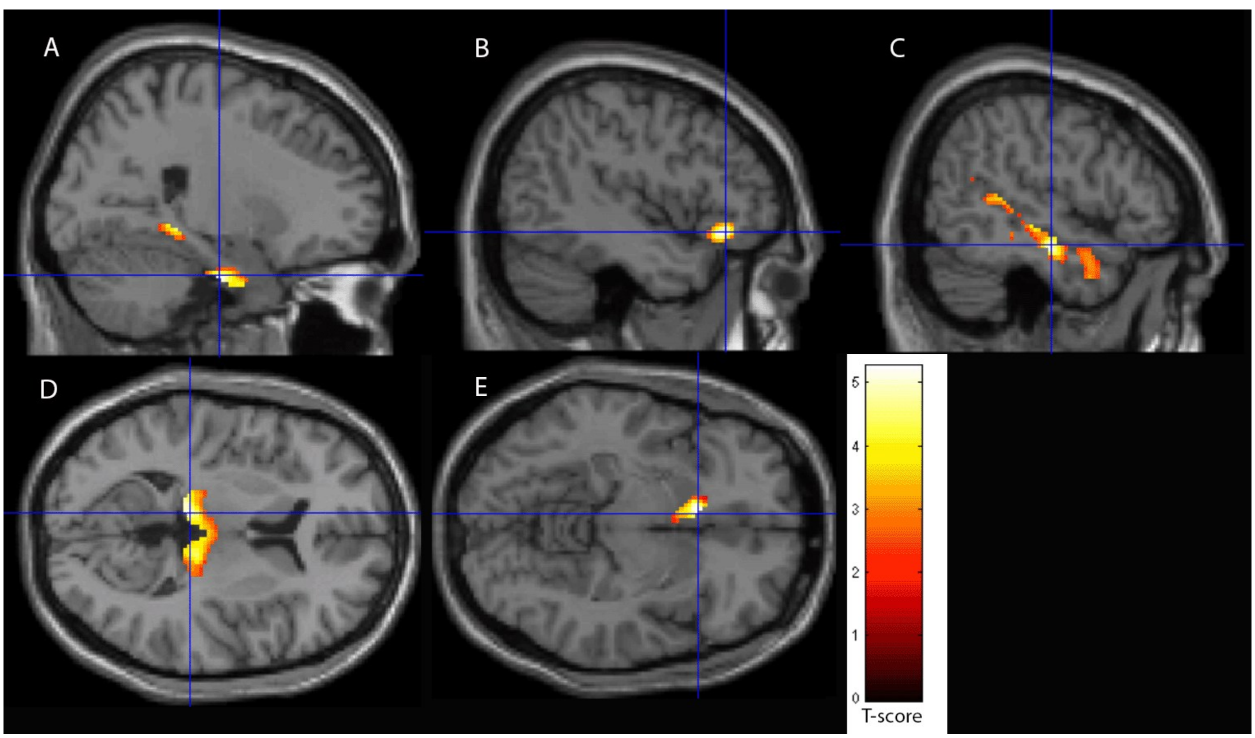
Table 1. Anxiety Provoking Task Results.

Contrast	Brain Region	MNI Coordinates	*T*-score	*p*-value
EVE group Post>Pre	R Superior Temporal Gyrus	48 -42 18	11.6	<0.001
Cluster Size - 8229	R Anterior Cerebellum	14 -54 -26	9.53	<0.001
	Middle Cingulate	8 -8 32	7.32	<0.001
	R Postcentral Gyrus	38 -28 54	7.09	<0.001

	R Middle Temporal Gyrus	52 -58 2	7.06	<0.001
	R Fusiform Gyrus	42 -54 -20	5.7	<0.001
Mindfulness group Post>Pre	Hippocampus	26 -14 -14	7.44	<0.001
Cluster Size - 6274	Caudate	6 8 -8	7.39	<0.001
	R Fusiform Gyrus	42 -12 -30	5.49	<0.001
	R Lingual Gyrus	14 -52 -4	5.40	<0.001
	L Inferior Temporal Gyrus	-58 -42 -18	5.07	<0.001
Cluster Size - 4629	R Supplementary Motor Area	14 -16 62	4.77	0.002
	L Paracentral Lobule	-10 -22 62	4.74	0.002
	L Precentral Gyrus	-34 -18 52	4.50	0.002
Post Intervention EVE>Mindfulness	Caudate	-6 18 -8	5.25	<0.001
Cluster Size - 12927	R Parahippocampal Gyrus	24 -14 -30	4.1	<0.001
	R Middle Temporal Gyrus	52 -14 -16	3.93	<0.001
	L Thalamus	-10 -30 8	3.92	<0.001
	Inferior Orbitofrontal Gyrus	-44 30 -10	3.39	<0.001
	R Temporal Pole	44 6 -28	3.75	<0.001
Post Intervention EVE>Controls	Bilateral Parahippocampal Gyrus	26 -2 -32	4.81	<0.001
		-24 -6 -30	3.96	<0.001

Cluster Size - 18106	Caudate/Medial Prefrontal Cortex	-6 16 -12	4.67	<0.001
	Bilateral Thalamus	-10 -30 8	3.92	<0.001
	Middle Temporal Gyrus	-62 -24 0	4.45	<0.001
	Superior Temporal Gyrus	54 -32 4	4.11	<0.001
	L Temporal pole	-50 6 -12	3.62	<0.001
	R Insula	44 0 0	3.61	<0.001

Figure 6. Anxiety Provoking Task Where EVE Post-intervention > Mindfulness Post-intervention.



Note: Five brain cross-section images (from a template provided by SPM12) with fMRI results from the anxiety-provoking task superimposed. Yellow, orange and/ or red areas, highlighted with blue crosshairs, depict brain regions where the EVE group showed significantly more activity than the mindfulness group post-intervention. Regions of Interest have the letters A, B, C, D, and E next to them, which depict the following brain areas: A) R parahippocampal gyrus, B) L inferior orbitofrontal gyrus, C) R middle temporal gyrus, D) Bilateral thalamus, E) L caudate. At the bottom right of the image, there is a legend that represents *T*-scores. This legend contains colours ranging from black (corresponding to a *T*-score of 0) to white (corresponding to a *T*-score of 5), with red, orange, and yellow in between 0 and 5). Lighter coloured brain regions correspond to higher *T*-scores and darker coloured regions correspond to lower *T*-scores.

N-back Task

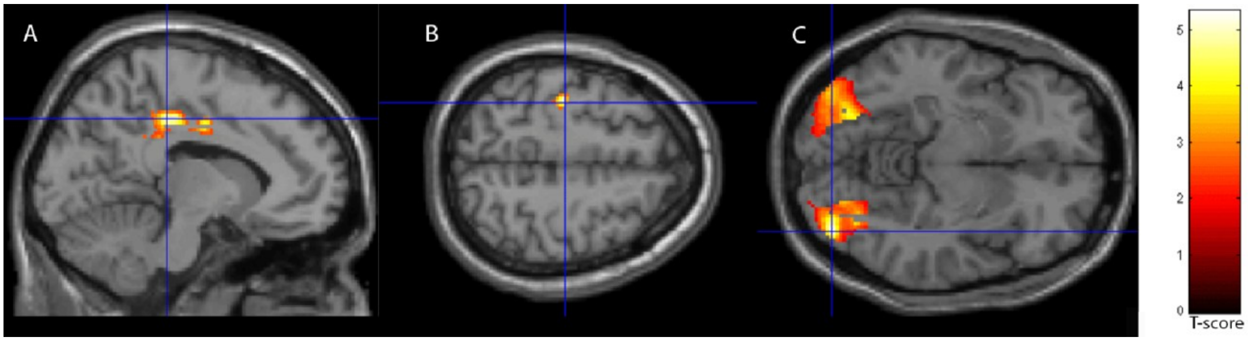
Paired samples *t*-tests revealed that, during the N-back task, the EVE group showed significantly more activity after the intervention compared to baseline in the midbrain, left middle temporal gyrus, cerebellum, putamen, and superior orbitofrontal frontal gyrus (Table 2). A three-way ANOVA revealed a significant group by time interaction. Independent samples *t*-tests showed that, post-intervention, the EVE group showed significantly less activity than the mindfulness group and the control group in various regions (Table 2). The EVE group differed from the mindfulness group in the middle cingulate gyrus and several visual areas, including the right cuneus, bilateral fusiform, bilateral inferior occipital gyrus, and left middle occipital gyrus, as well as the left precentral gyrus (Table 2, Figure 7). EVE participants showed similar patterns compared to controls (Table 2). The mindfulness group showed significantly less activity in visual areas compared to controls (bilateral cuneus, bilateral lingual gyrus, and bilateral superior occipital gyrus; Table 2).

Table 2. N-back Task Results

Contrast	Brain Region	MNI Coordinates	*T*-score	*p*-value
EVE group Post>Pre	Midbrain	8 -14 -16	10.45	<0.001
Cluster Size - 9774	L Middle Temporal Gyrus	-64 -46 -10	7.11	<0.001
	Cerebellum	10 -40 -18	6.96	<0.001
	Putamen	-20 14 8	5.87	<0.001
	Superior orbital frontal gyrus	-16 42 -20	5.85	<0.001
Post Intervention EVE<Mindfulness Cluster size - 7167	Bilateral Inferior Occipital Gyrus	40 -84 -8	5.32	<0.001
		-36 -84 -6	3.8	<0.001
	Bilateral Fusiform Gyrus	28 -72 -12	4.67	<0.001
		-28 -74 -12	4.61	<0.001
	L Middle Occipital Gyrus	-32 -92 10	4.07	<0.001

	R Cuneus	12 -96 14	3.89	<0.001
	L Middle Cingulate Gyrus	-10 -30 42	3.77	<0.001
	L Precentral Gyrus	-34 -20 56	3.71	<0.001
Post Intervention EVE<Controls	Cuneus	10 -94 18	6.13	<0.001
Cluster Size - 15293	R Inferior Occipital Gyrus	40 -84 -8	5.24	<0.001
	Bilateral Middle Cingulum	8 -20 42	5.11	<0.001
		-12 -6 42	4.93	<0.001
	Bilateral Superior Occipital Gyrus	16 -86 28	4.92	<0.001
		-16 -86 28	4.87	<0.001
	Fusiform	-26 -72 -4	4.75	<0.001
	Lingual Gyrus	-22 -70 -10	4.71	<0.001
Post Intervention Mindfulness<Controls	Bilateral Cuneus	6 -92 16	4.3	0.003
Cluster Size - 4292		-10 -94 18	3.48	0.003
	Bilateral Superior Occipital Gyrus	-20 -86 22	4.12	0.003
		16 -88 22	3.6	0.003
	Bilateral Lingual Gyrus	20 -70 2	4.11	0.003
		-20 -70 0	3.49	0.003

Figure 7. N-back Results where EVE < Mindfulness (and controls) post-intervention.



Note: Three brain cross-section images (from a template provided by SPM12) with N-back task results superimposed. Yellow, orange and red areas, highlighted with blue crosshairs, depict brain regions where the EVE group showed significantly less activity than the mindfulness group post-intervention. Regions of Interest have the letters A, B, and C beside them, which depict the following brain areas: A) middle cingulate, B) L precentral gyrus, C) visual regions. To the right of the three brain images, there is a legend that represents *T*-scores. This legend contains colours ranging from black (corresponding to a *T*-score of 0) to white (corresponding to a *T*-score of 5), with red, orange, and yellow in between 0 and 5). Lighter coloured brain regions correspond to higher *T*-scores and darker coloured regions correspond to lower *T*-scores.

N-back Task Performance

A 3 (group) x 2 (time) x 2 (condition) ANOVA also revealed changes in N-back task performance. There was a main effect of condition (F (1, 24) = 49.160, $p < 0.001$, ηp2 = 0.672). Post hoc pairwise comparisons showed that reaction times (RTs) were faster for Press for X than Press for 2-Back ($p < 0.001$).

There was also a significant interaction between group and time (F (2, 24) = 5.764, $p = 0.009$, ηp2 = 0.324). Specifically, the mindfulness group showed lower RTs than the control ($p = 0.002$) and EVE ($p = 0.012$) groups at time 2. The control group also showed higher RT at time 2 than time 1 ($p = 0.006$).

There was a time by condition interaction as well (F (1, 24) = 6.308, $p = 0.019$, ηp2 = 0.208). At time 1, RTs were higher for the 2-back condition than for Press for X condition ($p < 0.001$). This was also the case at time 2 ($p < 0.001$). RTs also increased from time 1 to time 2 ($p = 0.002$) for the Press for X blocks. Accuracy on the N-back task did not differ between groups, conditions, or time points.

General Discussion

The present study provides preliminary neuroimaging findings suggesting that the two-week EVE intervention produced significant effects on musicians with MPA during an anxiety-provoking task and a working memory task. Both qualitative (thematic) and quantitative (fMRI and questionnaire) results reveal EVE to be a promising new intervention that warrants further investigation. We found these results even without including the important outdoor element of EVE. The principles and techniques of this intervention may facilitate neural and behavioural changes indicative of reduced MPA, regardless of EVE taking place indoors or outdoors.

EVE and Mindfulness Effects on State Anxiety

The EVE and mindfulness groups showed significant decreases in STAI scores post-intervention. For the mindfulness group, both pre-and post-performance scores decreased, and for the EVE group, only pre-performance scores decreased. Interestingly, the EVE group's time two pre-performance STAI scores were significantly lower than their time one and time two post-performance scores. The mindfulness group also showed lower STAI scores post-performance at time two than pre-performance at time one; their STAI scores at time two pre-performance were also lower than time one post-performance. Additionally, before the intervention, the mindfulness group had significantly higher baseline STAI scores (pre-performance) than the no-intervention control group.

The EVE and mindfulness groups' decreases in pre-performance anxiety after their respective interventions suggests that both interventions provide techniques that are applicable to dealing with such anxiety. However, decreases in post-performance anxiety were observed only in the mindfulness group. This post-performance STAI score decrease suggests that mindfulness may have, through methods of non-reactivity and acting with awareness (Parkinson et al., 2019), modulated their anxiety after performing (e.g., being aware of the present moment rather than reacting to or ruminating about how they performed). The EVE group, being more focused on engagement before and during a performance (e.g., awareness of the space, sounds, and sensations), may not have experienced this post-performance anxiety reduction to the same degree as mindfulness. However, the STAI, being a subjective measure, depicts only perceived anxiety and can be prone to error. Such flaws in subjective measures emphasize the need for a combination of objective (brain imaging) and subjective (self-report) measures in evaluating the efficacy of EVE compared to that of mindfulness. The EVE group also only had seven participants while the mindfulness group had 10, neither sample size being large enough for sufficient power for this analysis.

Themes Evoked During EVE

Themes of internal and external present-moment focus speak to EVE's primary motivation to inspire a "noticing" through sensory input in the environment and engagement with the body (Oddy, 2022). To experience a full range of emotional involvement with the places they sang in, Oddy (2022) noted that an open mind is required to move beyond typical patterns of tonality, melody, vocal sounds, and rhythms. Participants from the current study showed this openness when allowing uncontrolled vocal output in response to other singers, directing attention toward the community of participants and away from internal feelings of control and anxiety. Such shifts were made possible by the present-moment co-development of musical structures in response to other singers. However, participants noted several constraints (e.g., time, vulnerability level, and vocal patterns) that may have impeded their ability to access a full range of emotional involvement.

Connections were revealed between participants and the environments they sang in, exemplifying "inter-material vibration," a term proposed by Eidsheim (2015) to represent the character music takes from materiality. According to Eidsheim's "vibrational" theory of music (2015), music is thought to be interconnected with the materiality of the place it is performed in;

performance is, therefore, affected by performance conditions. Participants' energetic, emotional, and physical responses to different aspects of their surroundings illustrate the importance of connecting with a performance space, as well as paying attention to perceptions of it. Through participants' connections with performance spaces, they seemed to engage more with their senses and less with anxious thoughts.

As noted by Oddy (2022), EVE is a practice of sonic-spatial exploration, where connectivity is central. As participants gained awareness of their relationships to objects and spaces, the idea of sound as a way of knowing (i.e., acoustemology) was exemplified. Acoustemology heavily implies reciprocity, between the self and all other life, human and non-human (Feld, 2015). As participants connected with their surroundings, EVE acted as a place-based sound making, involving heightened awareness of one's own connection to an environment as well as the environment's history (Feld, 2015). Such knowing through sound is thought to arise from participation (i.e., engagement with surroundings during practices) followed by reflection (i.e., group discussions after practices; Oddy, 2022).

Considering the entire body's involvement in singing (Cavarero, 2005; Sataloff, 1992), participants seemed to gain substantial awareness of the sensations of various vocal tones when connecting them to the body. For example, singing allows us to look within ourselves, at what is unfolding within our bodies (Oddy, 2022; Thomaidis & Macpherson, 2015); the personal, rootedness of the voice accounts for this, which is connected to our emotions and our lives in general (Uhlig, 2006). EVE appeared to evoke such inward focus through top-down attention to bodily sensations evoked by the voice. A couple of participants suggested that this top-down attention could be carried over to other forms of focus.

Participants' feelings of confidence near the end suggest that EVE is indeed a form of mindfulness and self-discovery (Oddy, 2022). In top-down awareness quotes, participants appeared to develop several skills for engaging with the body through voice and breath. Such top-down awareness (as was practiced in sessions one and two) led to participants' abilities to find areas of strength within their bodies that correspond to vibrational vocal sensations that indicate confidence (e.g., low, earthy tones felt in the strongest part of the body).

Influence of EVE and Mindfulness on Emotion Regulation During the Anxiety-Provoking Task

Compared to the mindfulness and no-intervention groups, the EVE group showed more activation in the caudate nuclei, the parahippocampal gyrus, and various temporal regions. Both the meditation styles of focused-attention and open monitoring have been associated with activation in a neural network including these regions, which are linked to self-awareness and self-regulation (Boccia et al., 2015; Fox et al., 2016; Wielgosz et al., 2019). Furthermore, themes from EVE participants' transcripts were self-referential (e.g., body, breath, and voice awareness; Boccia et al., 2015). EVE may overlap with and even surpass mindfulness techniques in the brain regions it targets, promoting regulation of negative emotions during music performance. EVE's activation of the vagus nerve (Yuen & Sander, 2017) may have amplified such emotional regulation. In decreasing negative emotions about musical performances, EVE may target brain regions responsible for emotional valence processing as well. Compared to the no-intervention group, the EVE group showed increased parahippocampal gyrus activation. Compared to the mindfulness group, the EVE group showed increased activation of both the parahippocampal gyrus and inferior orbitofrontal gyrus. This contradicts findings that mindfulness practices can decrease activation in these areas, due to their respective associations with arousal and default mode network activity (Kalyani et al., 2011; Lutz et al., 2014; Tomasino & Fabbro, 2016). However, previous findings of parahippocampal gyrus activation and orbitofrontal activation were observed during meditation (Boccia et al., 2015), and during mindfulness meditation-induced pain relief, respectively (Zeidan et al., 2015), arising from emotion regulation strategies targeting these regions. EVE participants may, therefore, have engaged in learned strategies while watching the videos of themselves performing that influenced emotion regulation (e.g., viewing music as playful and fluid).

Post-intervention, the mindfulness group may also have improved emotional regulation during the video task, but perhaps through different emotion regulation strategies: For example, non-reactivity (linked to precentral gyrus activation) and acting with awareness (linked to the activation of the fusiform, lingual, and inferior temporal gyri). Similar to the present study, Parkinson and colleagues (2019) found correlations between activation of these brain regions and the "non-reactivity" and "acting with awareness" dimensions of the Five-Facet Mindfulness Questionnaire.

EVE and Mindfulness Target Attentional Focus During the Anxiety Provoking Task

The EVE intervention may also impact attentional focus, as was revealed through the core theme of present moment awareness, and on a neurobiological level, corresponding to the EVE group's increased caudate activity post-intervention compared to the mindfulness group. The caudate nucleus is associated with motor activity, threat, and reward, and is a supporting part of the salience network (Peters et al., 2016). The salience network is responsible for refocusing one's mind when it wanders. It allows for the allocation of attention to task relevant stimuli and provides a homeostatic system that can maintain the most relevant task set and orchestrate switching between task sets (Menon & Uddin, 2010; Seeley, 2019). Refocusing attention is a key aspect of mindfulness techniques (Malinowski, 2013). The thalamus, another supporting part of the salience network, was also more strongly activated in the EVE group post-intervention than the Mindfulness group and the no-intervention control group. The thalamus is responsible for monitoring bottom-up sensory feedback; notably, it is involved in pain processing and awareness (including emotional arousal and discomfort; Nakata et al., 2014). Although a seemingly paradoxical finding, post-EVE thalamus activation could be explained by participants' enhanced modulation of bottom-up emotional arousal signals while watching their performances. EVE's focus on *engagement* with the environment and community (rather than simply *noticing* these things, as is done in mindfulness) may have strengthened its effects on the salience network.

EVE's emphasis on community and vulnerability during singing practices may account for this group's increased insula activation compared to the no-intervention group. The shared circuits hypothesis suggests that heightened activity in the insula is associated with both the acts of experiencing something firsthand and sharing others' experience (Eisenberger et al., 2003; Laneri et al., 2017). Such activation can represent interoceptive awareness of physiological arousal or affective experience (typically negative) and is strongly influenced by inter-individual differences in empathy. Our findings are consistent with Laneri et al. (2017) who found that anterior insula activity increased among participants who completed a mindfulness intervention involving empathetic sharing for people's embarrassing moments. Similarly, in Young et al.'s (2018) meta-analysis, participants who completed eight-week mindfulness-based interventions showed increased insular cortex activity, potentially because mindfulness promoted present-moment internal awareness. Sharing with others through both vocal experiences and reflections may facilitate present-moment focus and reduce past-or future-focus during performance.

Focus on the body and breath may be especially targeted by EVE, which was revealed through the themes of bottom-up body and breath awareness (i.e., in response to environmental input) and top-down body and breath awareness (i.e., self-regulated). The EVE group exhibited increased activity in the cerebellum following the intervention, which is involved in body awareness. The cerebellum's neuronal circuitry encodes mental representations of body movement (Ito, 2008). EVE participants' increased activation in this region may have arisen from heightened bodily and proprioceptive awareness post-intervention. Similarly, the mindfulness group showed increased SMA activation post-intervention, which may have been driven by body focus as well (Lhomond et al., 2019). The EVE group also revealed increased left temporal pole activity compared to the no-intervention control group, an area that receives input from the auditory pathway and contributes to auditory memory processing (Córcoles-Parada et al., 2019). The EVE group's increased cerebellum and temporal pole activity may have been due to increased sensory engagement with their performances from baseline to post-intervention.

Overall, the EVE intervention appeared to produce the most substantial increases in neural activation associated with present moment awareness and emotional regulation. The mindfulness program seemed to hover between EVE and no intervention, with higher contrasts in neural activation revealed in the EVE versus no-intervention than EVE versus mindfulness.

EVE's and Mindfulness' Effects on Cognitive Processing During Working Memory

In the N-back task, when engaging cognitive processing involved in working memory, the EVE group showed increased activity in areas devoted to motor and sensory function (cerebellum, putamen, midbrain), action-feedback monitoring (middle temporal gyrus), and working memory (superior orbitofrontal gyrus) from pre-to post-intervention. These activation patterns suggest enhanced coordination in responding to stimuli as well as heightened attention to the perceptual nature of stimuli. In Emch et al.'s (2019) fMRI meta-analysis of studies on healthy participants aged 18 to 75, activation of frontal gyri was linked to improved response inhibition and attentional control. The EVE group's higher superior orbitofrontal gyrus activation during working memory post-intervention may reflect superior ability to respond quickly and appropriately to executive demands during the task. The cerebellum and putamen have shown involvement in enhancing motor behaviours and suppressing undesired ones (Alexander et al., 1986; Emch et al., 2019; Mink, 1996). Midbrain nuclei have also shown involvement in initiation of motor sequences (Boecker et al., 2008), as are required in the N-back task. Additionally, the middle temporal gyrus may play a role in action-feedback monitoring, where these gyri detect conflict (e.g., non-matching or incongruent stimuli in the 2-back condition; van Kemenade et al., 2019). Through enhanced executive control, attentional focus, and monitoring post-EVE, the EVE group may have better controlled and suppressed their actions during the N-back task than the other groups.

Interestingly, the EVE group showed less activity than the other groups in cognitive processing (middle cingulate gyrus) and visual areas (cuneus, fusiform, inferior occipital gyrus, and middle occipital gyrus). The mindfulness group also showed less activity in visual areas (bilateral cuneus, lingual gyrus, and superior occipital gyrus) than controls. The EVE group's reduced activity in cognitive processing regions indicates less cognitive strain during working memory performance than the mindfulness and control groups. Similarly, the mindfulness group's reduced activity compared to the control group suggests that the mindfulness intervention also reduced cognitive strain during the N-back. This is consistent with the mindfulness group's reduced reaction time compared to the other groups for both Press for X and Press for 2-back conditions at time 2. Mindfulness novices have been found to require more cognitive effort to sustain attention on stimuli. Repeated mindfulness practice, however, reduces the effort required to sustain attention from improved attentional control (e.g., shifting attention from the breath to monitoring internal and external sensations; Brefczynski-Lewis et al., 2007; Falcone & Jerram, 2018). For example, a three-day intensive mindfulness meditation course improved resting state functional connectivity between executive and attentional brain areas (e.g., dorsolateral prefrontal cortex and inferior frontal gyrus; Taren et al., 2017). Alterations in the functional connectivity of these regions were also observed during the 2-back condition of the N-back task (Koshino et al., 2005). Through several facets of present-moment awareness strengthening attentional resources and inhibitory control, the EVE and mindfulness groups required less cognitive effort during working memory performance, with the EVE group displaying the most substantial benefits. These cognitive benefits could translate well to the context of music performance, considering the importance of directing attention towards the performance and responding appropriately to the executive demands of playing the piece.

Strengths, Limitations, and Future Directions

The present study sheds light on the neurobiological impact of traditional mindfulness and EVE on MPA. This study has several strengths, the first being its use of an active control mindfulness intervention to compare with the EVE intervention, along with the no-intervention control group. Furthermore, the present study added to the limited literature on longitudinal influences of mindfulness interventions on MPA. The mindfulness and EVE intervention's two-week timeframe has also been shown to be a sufficiently long enough intervention period to produce beneficial effects on anxiety (Berghoff et al., 2017), as was exemplified in the present study's STAI and neuroimaging results. Additionally, the brief, cost-effective nature of these interventions makes them accessible to a wide range of people who experience MPA.

It is also important to note some key limitations. One limitation is the study's sample size. Considering that most studies of the neurophysiological effects of mindfulness interventions have had small sample sizes, it is important for future studies to employ such methods among larger samples. In this preliminary study (with the goal to investigate whether EVE acts similarly to a mindfulness type intervention), we found significant effects of group and time on brain activity, suggesting that EVE is rooted in mindfulness and may even surpass traditional mindfulness techniques. Therefore, EVE warrants further investigation in larger scale studies. Furthermore, the distribution of males and females in the EVE group was uneven with only one male and six females. While this study targeted the population that may benefit most strongly from EVE and mindfulness (females, who often show higher MPA; Iusca & Dafinoiu, 2012), future studies with an even sex distribution should investigate the general impacts of EVE interventions on MPA.

Another important limitation is that some EVE participants were not able to attend all 10 sessions. All attended at least six but in future studies, researchers should ensure that participants can attend all sessions. Additionally, some participants spoke more than others during the discussions, pre-and post-EVE sessions. The thematic analysis was focused on themes that emerged across multiple participants; however, insights from participants who spoke more may have skewed the themes. Participants in the mindfulness group did not have transcripts recorded, which presents a further limitation to the thematic findings. Relatedly, only the mindfulness group was instructed to refrain from other mindfulness activities throughout the duration of the intervention. To ensure greater comparability between the groups' mindfulness activities outside of the interventions (or lack thereof in the case of the passive control condition), future studies should instruct all groups to refrain from mindfulness activities external to the study (or refrain completely for the duration of the study, in the case of passive control participants). Future studies should follow the same protocol for EVE and mindfulness interventions, where discussions held at the beginnings and ends of sessions are transcribed. This procedure will provide a basis for further thematic comparisons of EVE and mindfulness groups.

There were some aspects of the Anxiety-Provoking Task that may be adjusted in future research. For example, the same piece of music was performed and filmed for the Anxiety-Provoking Task pre-and post-intervention. However, all participants had the same procedure, thus controlling for variability in most aspects of their music-making process and task completion. Similarly, viewing their own recordings of the same piece during each scan, despite them being continuous from their performance, may have yielded attenuated self-critical thoughts by the third presentation. It could also be argued that as participants watched more of the video, they may have picked up on various aspects of their performance, with more opportunities to feel self-critical. Future studies might choose to have participants play different pieces pre-and post-intervention, to potentially enhance the anxiety provocation. They may also provide different clips for each of the blocks being presented.

Furthermore, the present study only included musicians with MPA as participants. To understand more precisely how musicians benefit from EVE and mindfulness interventions compared to the general public (as well as people in other performance-intensive professions), future studies should examine these effects among musicians (with and without MPA), people in other performing disciplines (with and without performance anxiety), as well as participants from the general public (e.g., healthy adults matched to the other groups for age and sex). Lastly, we only examined young adults in the present study. Despite MPA being most prevalent among young adults and adolescents, future studies should examine the effects of EVE and mindfulness on MPA in participants of various age groups, furthering our understanding of how such effects manifest across the lifespan. Finally, in our preliminary investigation of EVE, it is important to note that these sessions were carried out by the music therapist who developed the intervention. Future studies should investigate the replicability of the EVE protocol to see if EVE sessions conducted by other music therapists (trained on this protocol) have the same effects as those shown in the present study.

Conclusion

Both neuroimaging and qualitative findings reveal that EVE may be a valuable intervention to implement into the lives of musicians experiencing MPA. Our findings exhibit that the EVE intervention may, through both internal and external aspects of present-moment awareness, be as effective or even more effective than mindfulness in influencing brain activity. When participants with MPA watched videos of themselves performing with their instruments (compared to watching videos of another person performing with their own instrument), the EVE group showed increased activation in brain regions associated with emotional processing, attention, self-awareness, empathy, and executive control. EVE also may surpass mindfulness in reducing the cognitive effort needed to complete a working memory task. Based on both thematic analysis and neuroimaging results, EVE may exert its cognitive and emotional effects through focused attention and open monitoring that were drawn upon in the EVE intervention. While traditional mindfulness training also revealed several similar neural effects to those of EVE, mindfulness appears to hover between EVE and the no-intervention control condition in exerting such effects on emotional and cognitive processing during tasks. Through improved present-moment engagement with internal processes, the environment, and the community, EVE is an accessible, cost-effective method that could be applied as a mindfulness-type intervention for alleviating MPA. We all enjoy music, so why not try to ensure the musicians enjoy creating it.

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CHAPTER THREE: Preliminary rsfMRI evidence that mindfulness and improvisational singing can change the brain of musicians with performance anxiety

Boland, A. K., Oddy, N., Thorul, S., Boileau, K., Fang, L., Stanson, N., Comeau, G., & Smith, A. M. (2025). Preliminary rsfMRI evidence that mindfulness and improvisational singing can change the brain of musicians with performance anxiety. *International Journal of Music, Health, and Wellbeing* (IJMHW). Autumn 2025. www.musichealthandwellbeing.co.uk ISSN2515-981X. Article link: https://tinyurl.com/2vsevxd7

Abstract

Music performance anxiety negatively impacts musicians' mental health and can lead to devastating outcomes such as career abandonment and substance use. Considering the powerful impact of music on society, supporting musicians' wellbeing is crucial. We conducted a preliminary investigation of how two weeks of a mindfulness-based vocal improvisation program called Environmental Vocal Exploration or EVE (Oddy, 2022) influenced the brain activity of musicians with performance anxiety. The EVE intervention was conducted in a group setting by a certified music therapist, involving engagement with the body, breath, and surroundings while vocalizing with the group. We also investigated the neural effects of a traditional mindfulness intervention as an active control condition. Before and after the interventions, we used functional Magnetic Resonance Imaging (fMRI) to examine the brain activity of 27 18–28-year-old musicians during a five-minute resting state scan, while participants were not engaged in a cognitive task (n=10: traditional mindfulness, n=7: EVE, n=10: no intervention). Following both interventions—particularly EVE—participants showed alterations in brain networks devoted to attentional control as well as emotion regulation. EVE's benefits may exceed those of traditional mindfulness by increasing engagement with body sensations and surroundings. Additionally, EVE necessitates vocalization, which can reduce stress by stimulating the vagus nerve. Such present moment awareness and stress reduction could improve musicians' ability to manage the executive demands of musical performance. Our preliminary findings indicate that EVE may benefit mental health among musicians who experience performance anxiety.

Keywords: Music Performance Anxiety; Mindfulness; Environmental Vocal Exploration; fMRI; neuroscience

Introduction

Music Performance Anxiety and Mindfulness

While it is well known that music has a significant positive impact on society, few studies have examined the well-being of musicians themselves. Professional musicians and students alike face poorer mental health than the general workforce (Detari, Egermann, Vaag, and Bjerkeset, 2020; Kegelaers, Schuijer, and Oudejans, 2021; Gross & Musgrave, 2020; Vaag, Bjørngaard, and Bjerkeset, 2016; Vaag, Saksvik-Lehouillier, Bjørngaard, and Bjerkeset, 2016) and students in other disciplines (Ginsborg, Kreutz, Thomas, and Williamon, 2009; Panebianco-Warrens, Fletcher, and Kreutz, 2015; Vaag, Bjerkeset, and Sivertsen, 2021), respectively. Music performance anxiety or MPA is a significant contributor to such problems (Kenny, 2011; Orejudo Hernández, Zarza-Alzugaray, and Casanova, 2018), which can have devastating effects, including substance use and career abandonment (Orejudo Hernández et al., 2018). There is thus a strong need for accessible, cost-effective methods for improving musicians' mental wellness.

Music Performance Anxiety involves marked, persistent apprehension toward musical performance (Kenny, 2011: 433). Manifestations of MPA include anxious cognitions and behaviours as well as autonomic arousal (Craske & Craig, 1984; Kenny, 2005: 185). This type of anxiety is highly debilitating for a wide range of musicians (Kenny, 2006; 2011) and can impact all domains of musicians' functioning (for example, personal and professional; Zhukov, 2019). For example, a systematic review by Fernholz, Mumm, Plag, Noeres, Rotter, Willich, Ströhle, Berghöfer, and Schmidt (2019) found that between 16 and 59% of examined musicians experienced severe MPA and about 60% experienced some type of MPA at least once in their career.

Mindfulness practices, a family of emotional and attentional regulatory practices that involve purposeful, non-judgmental attention to the present moment (Kabat-Zinn, 2003: 145), have implications for wellness due to their versatility, diversity, and focus on resilience and well-being (Weilgosz, Goldberg, Kral, Dunne, and Davidson, 2019). Mindfulness has been applied to a variety of mental health disorders, including anxiety and depression, showing high effectiveness in reducing symptoms (Khoury, Sharma, Rush, and Fournier, 2015; Zhang, Lee, Mak, Ho, and Wong, 2021). Mindfulness practices have been shown to enhance emotional regulation in young musicians experiencing MPA (for example, Chang, Midlarsky, and Lin, 2003; Diaz, 2018), through processes such as improved awareness of one's internal processes (Gibson, 2019) and decreased emotional reactivity towards negative stressors (Britton, Shahar, Szepsenwol, and Jacobs, 2012). To understand the mechanisms through which mindfulness can influence musicians' thought patterns, feelings, and overall psychosocial well-being, this paper aims to investigate these effects on a neurobiological level.

Resting state functional magnetic resonance imaging (rsfMRI) is a brain imaging technique that measures neural activity while a person is not engaged in a cognitive task. This technique can provide valuable information on the functional connectivity (communication) between different brain regions, which is measured by correlations between the activity of different regions, within and between neural networks. Resting state FC can shed light on how mindfulness may impact the emotional and attentional regulation of musicians with MPA.

One brain network that has been shown to be altered following mindfulness interventions is the default mode network (DMN; Rahrig, Vago, Passarelli, Auten, Lynn, and Brown, 2022). The DMN is implicated in mind-wandering, creativity, and rumination and includes the following brain regions: medial prefrontal cortex (mPFC), posterior cingulate cortex (PCC), posterior/lateral parietal cortices, and parahippocampal gyrus (Buckner, Andrews-Hanna, Schacter, 2008; Hasenkamp, Wilson-Mendenhall, Duncan, and Barsalou, 2012; Malinowski, 2013; Menon, 2023). Another network affected by mindfulness is the salience network (SN), which plays a role in detecting stimuli that are most relevant and includes the anterior cingulate cortex (ACC), anterior insula, and anterior PFC (Hasenkamp et al., 2012). The frontoparietal or central executive network (CEN) is also altered by mindfulness. This network involves the PFC and posterior parietal cortex and is implicated in goal-oriented attentional engagement (Hasenkamp et al., 2012). Together, the DMN, SN, and CEN can communicate to produce mindful attentional awareness, with the SN recognizing mind-wandering within the DMN, and the CEN disengaging from distraction and orienting attention back to the present moment

(Malinowski, 2013). In Rahrig and colleagues' (2022) meta-analysis that investigated the effects of mindfulness-based training programs on the resting state FC (rsFC) of these networks, 12 studies showed that after mindfulness interventions, participants showed greater rsFC between regions of the SN and DMN (for example, Bremer, Mora Álvarez, Hölzel, Wilhelm, Hell, Tavacioglu, Torske, and Koch, 2022; Kwak, Lee, Jung, Hur, Bae, Hwang, Cho, Lim, Kim, Park, and Kwon et al., 2019). One study within this meta-analysis showed that experienced meditators had greater rsFC in the PCC (within the DMN), dorsal ACC (within the SN), and dorsolateral PFC (within the CEN) than meditation-naive controls (Brewer, Worhunsky, Gray, Tang, Weber, and Kober, 2011; Rahrig et al., 2022).

Mindfulness can also influence rsFC in various limbic regions of the brain. For example, limbic regions such as the amygdala and the hippocampus play a key role in emotional processing and affective state (Way, Creswell, Eisenberger, and Lieberman, 2010). The amygdala has shown increased resting state activity in people suffering from depression, and dispositional mindfulness is associated with reduced resting amygdala activity (Way et al., 2010). The hippocampus plays a vital role in modulating amygdala activity during attentional and emotional regulation as well as modulating cortical arousal and responsiveness (Hölzel, Carmody, Vangel, Congleton, Yerramsetti, Gard, and Lazar, 2011). Hölzel and colleagues (2011) found that among meditators, the hippocampus showed high grey matter concentration, which was suggested to be due to this modulatory role.

Among people with generalized anxiety disorder, which can act as a predictor of MPA (Wiedemann, Vogel, Voss, and Hoyer 2022), Zhao, Chen, Kang, Liu, Bai, Cao, Cheng, Xu, and Zhang (2019) found that an eight-week mindfulness-based cognitive therapy intervention led to increased rsFC between the PCC (DMN) and both the ACC and insula (SN). These FC patterns were correlated with reduced anxiety. Similarly, following a three-day intensive mindfulness meditation program, job-seeking adults experiencing stress showed increased rsFC between the PCC (DMN) and left dorsolateral PFC, a region involved in executive control (Creswell, Taren, Lindsay, Greco, Gianaros, Fairgrieve, Marsland, Brown, Way, Rosen, and Ferris, 2016).

Further research on the effects of mindfulness on rsFC is warranted in the context of anxiety. Specifically, there is a gap in our knowledge of how mindfulness techniques influence communication within the brains of musicians with MPA. Boileau, Stanson, Fang, Barbeau, Hansen, Comeau, and Smith (2024) investigated these effects among 20 musicians with MPA, ten of whom completed two weeks of mindfulness training, reminiscent of a mindfulness-based stress reduction program, and the other ten completed no intervention. Boileau and colleagues found that, post-intervention, participants in the Mindfulness group showed lower rsFC between the lateral prefrontal cortex (within the CEN) and two cerebellar regions involved in emotional processing. These reduced connections are characteristic of acceptance (Goldin, Moodie, and Gross, 2019), which is a key component of mindfulness, ultimately suggesting that mindfulness may have strengthened musicians' emotion regulation abilities. The current project seeks to build on these findings by investigating the rsFC of young adults with MPA who completed a two-week mindfulness-based vocal improvisation practice called Environmental Vocal Exploration (EVE).

Environmental Vocal Exploration

Environmental Vocal Exploration (EVE) is an intervention developed by Nicola Oddy, a certified music therapist, who researched the effects of place on a person's experience of their self, and the effects of their understanding of, and connection to place. EVE is a practice in which participants engage in vocal improvisation and through that act, explore their personal responses to different environments. During the improvisations, participants are guided to direct attention inwardly (to one's own body, breath, and emotional state) and outwardly (to the environment and the people around oneself). It was initially developed as a performance practice and as a therapy practice (Oddy 2022, 2024). Once developed, Oddy began using this construct as a mindfulness practice and saw how it could help performers to develop positive relationships with their instruments, the act of performing, and their performance environments (Boland, Boileau, Oddy, Welch, Stanson, Comeau, and Smith, 2025). She also saw that it could help to reduce musicians' performance anxiety. Sharing all foundational aspects of mindfulness training, EVE's effectiveness and impact on MPA appear promising.

Boland et al (2025) recently conducted a preliminary investigation of how two weeks of EVE could influence the brain activity of young musicians with MPA compared to two weeks of a more traditional mindfulness program. Before and after these two programs, Boland and colleagues (2025) used fMRI to examine musicians' brain activity while 1) watching videos of themselves performing and 2) completing a task of working memory, a crucial skill for musicians that is negatively impacted by anxiety (Meinz & Hambrick 2010; Schmeichel, Volokhov, and Demaree, 2008). A thematic analysis was also conducted on transcripts from discussions that participants had before and after EVE sessions. Both traditional mindfulness and EVE appeared to promote increased activity in attentional (Menon & Uddin, 2010; Seeley, 2019) and emotional regulation brain regions (Boccia, Piccardi, and Guariglia, 2015; Fox, Dixon, Nijeboer, Girn, Floman, Lifshitz, Ellamil, Sedlmeier, and Christoff, 2014), in line with themes related to present moment awareness that emerged. These effects were most prominent in the EVE group, perhaps because vocalizing activates the vagus nerve, which has been linked with stress reduction (Yuen & Sander, 2017).

The Present Study

Our goals for the present study were to 1) investigate changes in musicians' rsFC after two weeks of EVE sessions and 2) compare the neural activity of the EVE group to that of a similar group of musicians who underwent a 2-week traditional mindfulness intervention (Boileau et al., 2024; Boland et al., 2025), and a passive control group who completed no intervention.

Methods

Participants

Twenty-seven musicians (ages 18-28, M = 23.1, SD = 2.68) with MPA participated in the study. The first ten registered participants were allocated to an active control group (i.e., mindfulness intervention), the following ten to a passive control group (i.e., no intervention) and the last seven to an experimental group (i.e., EVE intervention). These participants were recruited from a larger sample in another study (Stanson, Comeau, Smith, Swirp, 2022) and are identical to the participants in Boileau et al. (2024) and in Boland et al. (2025).

Participants who had achieved grade seven from the Royal Conservatory of Music, who had completed or who were currently in the process of completing a post-secondary degree program in music were included in the study. Instruments played by participants included the piano (n = 8), the violin (n = 4), percussion (n = 2), the flute (n = 1), the viola (n = 1), the bagpipes (n = 1), the clarinet (n = 1), the French horn (n = 1), the guitar (n = 1), the trumpet (n = 1), cello (n = 1), bassoon (n = 1), double bass (n = 1), saxophone (n = 1), and vocals (n = 2). Participants' mean starting age for their instruments was 9½ years of age. There were no significant demographic differences between groups.

Participants were excluded if they engaged in any kind of formal training in mindfulness, if they had psychological disorders that they were currently being medicated for and/or if they were ineligible for MRI scans (i.e., had non-removable metal in their body or implanted devices, were claustrophobic etc.). See Table 1 for participant demographic information.

Table 1.

Participant Demographics

Condition	**Mean age**	**Sex**	**Mean baseline KMPAI Score**	**Mean baseline STAI Score**	**Mean instrument starting age**	**Mean number of years in music lessons**
Mindfulness	24.4 (SD = 2.6)	5 males; 5 females	61% (SD = 5.8%)	48.3 (SD = 10.1)	9 and ½ (SD = 5.9)	12.8 (SD = 6.7)
EVE	22.05 (SD = 1.6)	1 male; 6 females	52% (SD = 23.5%)	43 (SD = 14.05)	8 (SD = 3.6)	12 (SD = 4.3)
Control	22.6 (SD = 3.13)	5 males; 5 females	44.7% (SD = 16.4%)	36.2 (SD = 9.7)	10.8 (SD = 2.9)	11.1 (SD = 2.6)

Measures

Demographic and Health Questionnaire

Demographic and health information regarding participants' age, sex, previous experience with mindfulness activities (for example, yoga, meditation, and mindfulness-based stress reduction), as well as pre-existing psychological conditions or history of substance use were collected. In addition, information was collected regarding participants' music backgrounds such as the instruments they play, the number of years in music lessons, the age they started formally studying music, and the highest music degree attained.

Spielberger State-Trait Anxiety Inventory

Music performance anxiety was measured using the state anxiety subscale in the Spielberger State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, and Jacobs, 1983). This state anxiety subscale contains 20 questions, asking participants to rate the extent to which they currently resonate with statements such as 'I feel at ease' and 'I feel strained.' Participants provided their responses on a 4-point Likert scale, ranging from one (not at all) to four (very much so). The STAI has been employed in MPA studies (for example, Brooker, 2018; Spahn, Echternach, Zander, Voltmer, and Richter, 2010) and studies on mindfulness training (for example, La Torre, Raffone, Peruzzo, Calabrese, Cocchiara, D'Egidio, Leggieri, Dorelli, Zaffina, Mannocci, and YOMIN Collaborative Group, 2020). Furthermore, the scale has a high internal consistency, with Cronbach's alpha coefficients ranging from 0.86 to 0.95 (Spielberger et al., 1983).

Kenny Music Performance Anxiety Inventory (KMPAI) – Revised

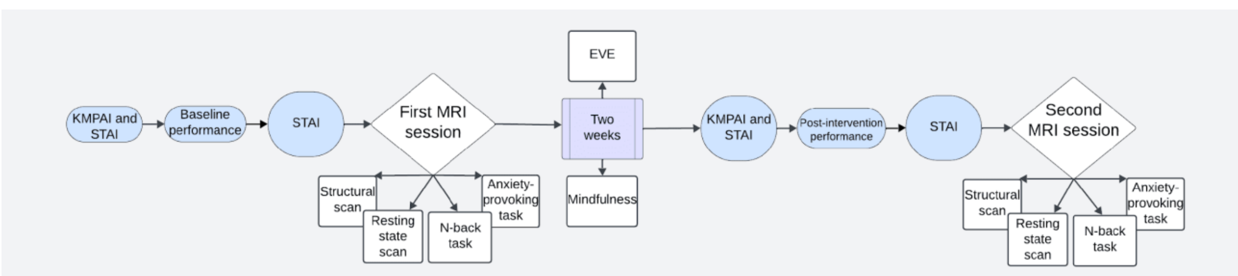
Participants completed the KMPAI (D. Kenny, 2009) as a measure of baseline and post-intervention music performance anxiety. The revised KMPAI contained 40 items within eight domains of performance anxiety: Somatic Anxiety/Worry about Performance, Worry Focused on Self/Other Scrutiny, Depression/Hopelessness, Parental Empathy, Memory, Trait Anxiety, Anxious Apprehension, and Biological Vulnerability. Scores are expressed as percentages, with higher domain-specific and total scores indicating higher levels of MPA.

Procedure

Participants first completed the demographic and health questionnaire as well as the KMPAI (Kenny, 2009). Before and after performing at the first study session, they also completed the state anxiety subscale of the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983). This took place within seven days (M = 6.7, SD = 2.3) of the first imaging session. The STAI was administered prior to and following a performance with their instrument in front of a mock jury. Participants underwent a one-hour MRI session with the parameters and results from only the resting state fMRI being reported below. Following their respective experimental conditions, participants underwent the same procedure. See Figure 1 for a timeline of the full study procedure.

Figure 1.

Procedural timeline



EVE Intervention Procedure

EVE was developed to explore any kind of environment; however, the initial study took place in a variety of places, including outside in nature, on a city street, on a busy road, at a dam site, and in a reverberant tunnel. These outdoor locations were chosen because COVID prevented indoor singing. During the current study, however, the practice took place entirely indoors, since we sought to compare it to a previously led mindfulness group that took place inside. This was done in an attempt to keep as many variables as similar as possible between the groups. Ten group EVE sessions took place in three rooms of the University and were led by the certified music therapist who developed EVE.

The first three sessions involved directing attention to various parts of the body while lying down on mats, breathing and singing *into* these body parts, sending them nurturance, acceptance, and gratitude as a foundation for self-exploration. The fourth and fifth sessions involved sitting and walking meditations, directing attention towards the body, the room, and the outside world, while also considering (metaphorically) what they could give to and receive from the earth. During these sessions, participants engaged in vocal 'parallel play,' vocalizing at the same time but not in unison. Sessions six through eight emphasized community, where participants did their own singing while listening to others and creating joint melodies, singing in a drone while one person at a time improvised over the drone, and exploring sonic properties and singing along with instruments that were sometimes in the rooms, such as gongs, drums, and a piano. The ninth session emphasized reciprocity between participants' bodies and their external surroundings as well as between themselves and the other singers; this session also included a spontaneous droning experience in an improvisation circle at the end. During the last session, the musicians explored the guttural parts of their voices, focusing on the power they could foster within their bodies. All EVE sessions ended with activities for participants to process their experiences such as mandala drawing, body scans, song writing, and further improvisational singing. There was always a group discussion afterward, when people could consider feelings that arose, and applications for the mindfulness skills learned throughout this experience. For information on the genesis of EVE, see Oddy (2022).

Mindfulness Intervention Procedure

The mindfulness intervention involved a two-week training program, which comprised ten one-hour sessions. Sessions were conducted in a group format, by a registered Mindfulness-Based Cognitive Therapy facilitator. Each session consisted of meditation exercises including body scanning, breath awareness, mindful walking, qigong, and discussion groups. There were also discussion groups during sessions focused on participants' daily stresses, their experiences with mindfulness training so far, and their past experience with MPA.

fMRI Procedure

Data was acquired on a 3.0 Tesla Siemens Biograph MR-PET scanner using a 12-channel head coil. All participants went through the same scanning procedure. Resting state fMRI images were obtained using T2* weighted echo-planar sequences covering the full brain (TR = 3000 ms, TE = 27 ms, flip angle = 90º, FOV = 24 cm, 64x64 matrix, slice thickness = three mm, 48 axial slices, bandwidth 62.5 kHz). During the scan, participants lay on the bed of the scanner for five minutes and nine seconds and were given the following instructions: 'Relax and try not to think about anything in particular. Keep your eyes closed until the scan is over. The scan will take about five minutes.' A T1-weighted spin echo localizer was acquired to confirm positioning. This localizer was used to prescribe the subsequent T1-weighted 3D multi-echo magnetization prepared rapid acquisition gradient echo (MEMPRAGE) sequence (TR = 11.2 ms, TE = 21 ms, flip angle = 60°, FOV = 26 cm, 256x256 matrix, slice thickness = 1.5 mm) for further analyses (van der Kouwe, Benner, Salat, and Fischl, 2008).

Data analysis

Functional Connectivity Analysis

The default pipeline in the CONN toolbox was used to perform preprocessing steps of functional images such as realignment, co-registration, smoothing (6mm FWHM kernel). To remove of nuisance signals originating from white matter and cerebrospinal fluid, signals were regressed out by estimating five potential noise components (Chai, Castañón, Öngür, Whitfield-Gabrieli, 2012). Head motion effects were identified and regressed out from realigned data using the Friston 24-parameter model. Scrubbing, involving the removal of problematic data points, was conducted using artifact detection tools. Data points that met the global-signal threshold (z-value above 5) and subject-motion threshold (above 0.9 mm) were considered problematic. Moreover, the account for differences in head motion between groups, head motion and scrubbing parameters were included as covariates in the first-level analysis. Additionally, linear and quadratic trends were also included as regressors to address the low-frequency drifts in the BOLD signal. Temporal filtering was applied on the time series to target the relevant frequences between 0.008–0.09 H. Finally, using a seed-to-voxel FC analysis approach, correlation coefficients between the time series of seed regions (Table 2) and all other voxels in the whole brain were calculated. Correlation coefficients were then transformed into z scores using Fisher's r-to-z transformation.

Table 2.

Networks and Seed Selection

Default Mode Network (DMN)	Bilateral Medial prefrontal Cortex (mPFC) Bilateral Posterior cingulate cortex (PCC) Bilateral lateral parietal lobe (LP)
Salience Network (SN)	Bilateral insula Anterior cingulate cortex (ACC)
Frontoparietal network (CEN)	Bilateral lateral prefrontal cortex (lPFC),
Emotional Processing Regions	Bilateral amygdala Bilateral thalamus Bilateral hippocampus

Group analysis

To analyze group differences (i.e., EVE condition, mindfulness condition and no intervention condition), time differences (i.e., before and after 2-week intervention) and interactions between Group and Time, a two-by-two mixed model ANOVA analysis was conducted on the resting state networks' FC for each seed (see Table 2). The significance threshold was set as uncorrected $p < 0.005$ at the whole brain level, and False Discovery Rate-corrected (FDR-corrected) $p < 0.05$ at the cluster level. Post-hoc simple t-tests were performed using a Region of Interest to Region of Interest (ROI-to-ROI) approach for the regions that showed significant main effects or interaction effects.

Results

Default Mode Network

As shown in Figure 2A, a significant interaction effect (Group × Time) was found in the rsFC between mPFC seed and left paracingulate gyrus (PaCiG). Follow-up post-hoc tests revealed that from pre- to post-intervention, the EVE group showed increased rsFC between the mPFC seed and the left paracingulate gyrus (see Figure 3A).

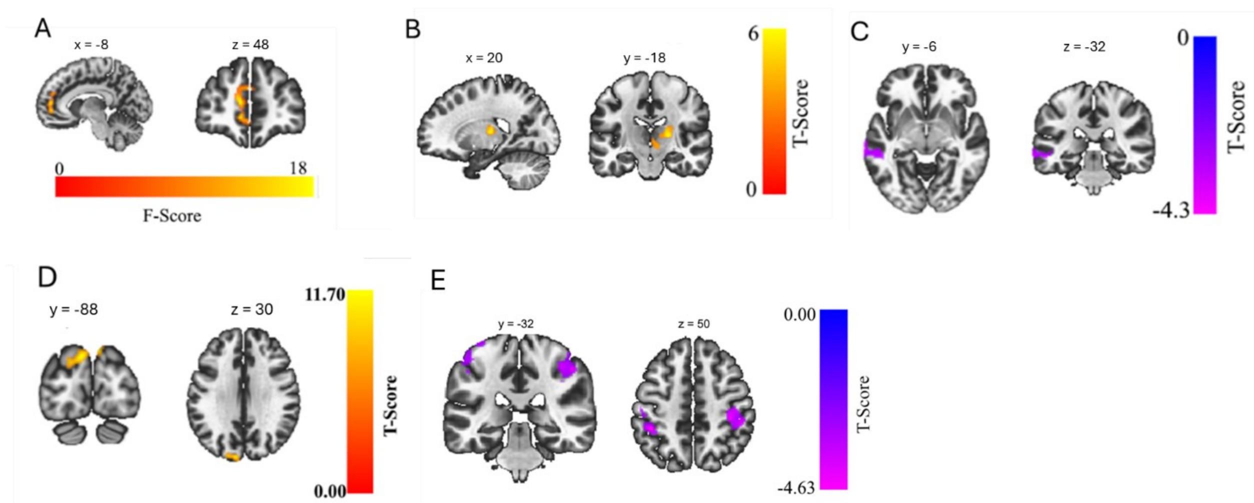
There was also a significant Time effect, shown in Figure 2B, where rsFC between mPFC and the right thalamus increased from pre- to post-intervention. Post-hocs revealed that from pre- to post-intervention, both the EVE and Mindfulness groups showed increased rsFC between the mPFC seed and the right thalamus (see Figure 3B). As shown in Figure 2C, there was another significant time effect where rsFC decreased from pre- to post-intervention between mPFC and the left middle temporal gyrus. Post-hocs showed that both the EVE and Mindfulness groups, as well as the Control group, also showed decreased rsFC between the mPFC and left middle temporal gyrus from pre- to post-intervention (see Figure 3C).

There was also a group effect between the PCC seed and right occipital pole across both time points, as is shown in Figure 2D. Compared to both the Mindfulness and Control groups, the EVE group showed lower rsFC between the PCC seed and the right occipital pole at both time points (see Figure 3D).

Finally, as shown in Figure 2E, there was a time effect where rsFC decreased between the bilateral LP and the bilateral postcentral gyrus from pre- to post-intervention. Post-hoc tests illustrated that EVE participants showed a decrease in rsFC from pre- to post-intervention between bilateral LP seeds and bilateral postcentral gyrus (see Figure 3E and Figure 3F).

Figure 2.

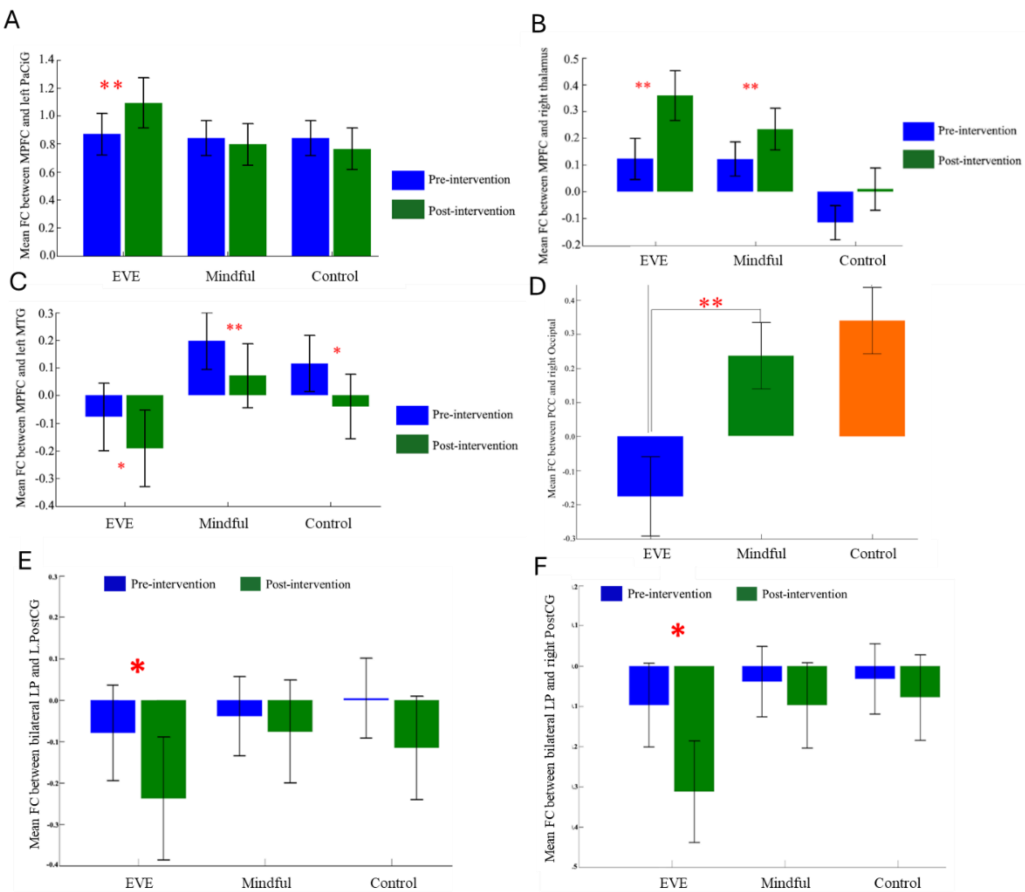
Resting state Functional Connectivity in the Default Mode Network: Main Group and Time Effects



Note: A) Group x Time interaction in rsFC between MPFC seed and left paracingulate gyrus; B) Post-intervention > pre-intervention: rsFC between MPFC and the right thalamus; C) Pre-intervention > post-intervention: rsFC between MPFC and the left middle temporal gyrus; D) Group effect between the PCC seed and right occipital pole across both time points; E) Pre-intervention > post-intervention: rsFC between the bilateral LP and the bilateral postcentral gyrus.

Figure 3.

Resting state Functional Connectivity in the Default Mode Network: Post-hoc Tests



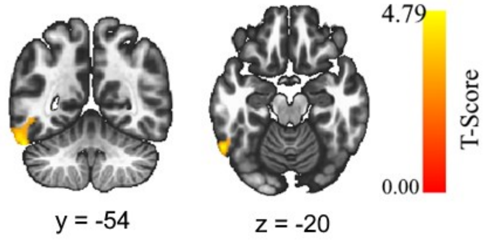
Note: A) EVE post-intervention > pre-intervention: mPFC seed and left paracingulate gyrus; B) EVE and Mindfulness post-intervention > pre-intervention: mPFC seed and right thalamus; C) EVE, Mindfulness, and Control group post-intervention > pre-intervention: mPFC seed and left middle temporal gyrus; D) Mindfulness and Control > EVE: PCC seed and right occipital pole; E) EVE pre intervention > post-intervention: bilateral LP seeds and left postcentral gyrus; F) EVE pre intervention > post-intervention: bilateral LP seeds and right postcentral gyrus.

Salience Network

As shown in Figure 4, there was a significant time difference in the rsFC between the bilateral insula seed and the left inferior temporal gyrus (L.ITG). Specifically, post-intervention rsFC was greater than pre-intervention. Follow-up post hoc tests revealed that, from pre- to post-intervention, the EVE group showed increased rsFC between the insula seeds and left inferior temporal gyrus (see Figure 5).

Figure 4.

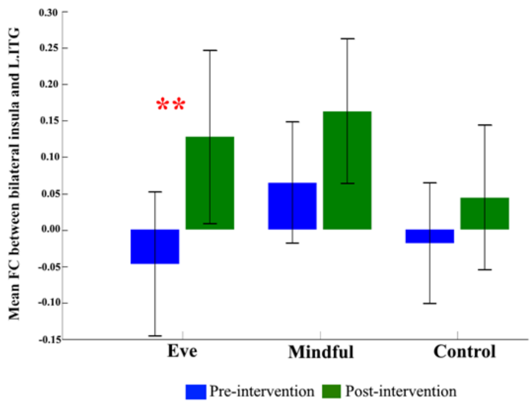
Resting state Functional Connectivity in the Salience Network: Main Group and Time Effects



Note: Post-intervention > pre-intervention: rsFC between the bilateral insula seed and the left inferior temporal gyrus.

Figure 5.

Resting state Functional Connectivity in the Frontoparietal Network: Post-hoc Tests



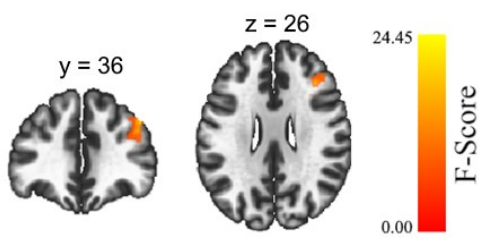
Note: EVE post-intervention > pre-intervention: bilateral insula seeds and left inferior temporal gyrus.

Frontoparietal Network

As shown in Figure 6, significant interaction effects (Group × Time) were found in the rsFC between the bilateral lPFC seed and the right middle frontal gyrus (R.MidFG) as well as the right PostCG. Post-hoc tests showed that EVE participants showed decreased rsFC between the bilateral lPFC and right middle frontal gyrus and the right postcentral gyrus from pre- to post-intervention (see Figure 7).

Figure 6.

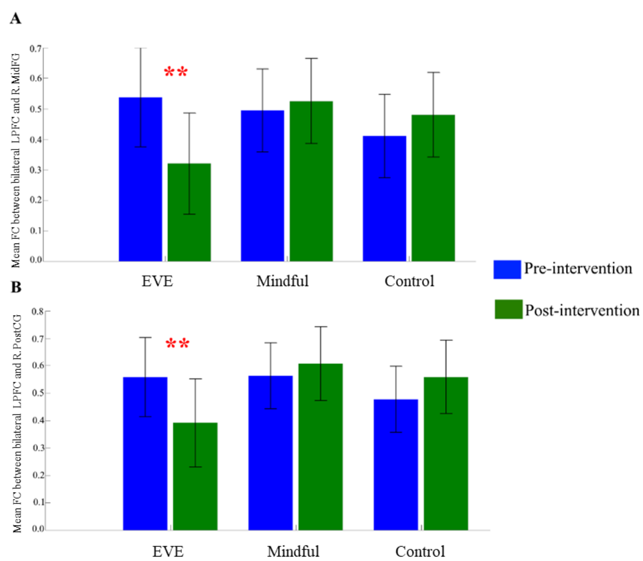
Resting state Functional Connectivity in the Frontoparietal Network: Main Group and Time Effects



Note: Group × Time interaction in rsFC between the bilateral lPFC seed and the right middle frontal gyrus as well as the right PostCG.

Figure 7.

Resting state Functional Connectivity in the Frontoparietal Network: Post-hoc Tests



Note: A) EVE pre-intervention > post intervention: bilateral lPFC and right middle frontal gyrus; B) EVE pre-intervention > post intervention: bilateral lPFC and the right postcentral gyrus.

Emotional Processing Regions

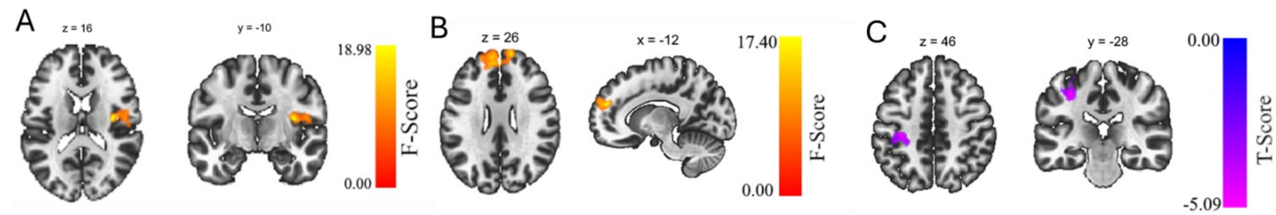
A significant group effect was observed between the bilateral amygdala seed and right central opercular cortex (R.CO) across both time points (Figure 8A). Post-hoc tests revealed that, compared to both the Mindfulness and Control groups, the EVE group showed decreased rsFC between the bilateral amygdala seeds and right central opercular cortex across both time points, as is shown in Figure 9a.

A significant group effect was also observed between the bilateral thalamus seed and bilateral frontal pole (FP) across both time points (Figure 8B). Post-hoc tests revealed that the EVE and Mindfulness groups showed increased rsFC between the bilateral thalamus seeds and bilateral frontal pole compared to the Control group at both time points.

Finally, a significant time difference was found in the FC between the bilateral hippocampus seed and the left PostCG. Specifically, post-intervention FC was decreased compared to pre-intervention. Post-hocs revealed that from pre- to post-intervention, the EVE group showed significantly decreased rsFC between the bilateral hippocampus seeds and left postcentral gyrus.

Figure 8.

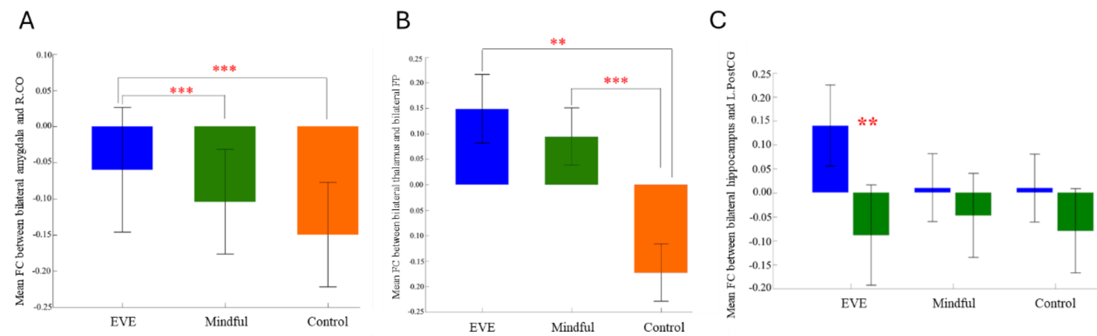
Resting state Functional Connectivity in the Emotional Processing Regions: Main Group and Time Effects



Note: A) Group effect between the bilateral amygdala seed and right central opercular cortex across both time points; B) Group effect between the bilateral thalamus seed and bilateral frontal pole across both time points; C) Pre-intervention > post intervention: rsFC between the bilateral hippocampus seed and the left PostCG.

Figure 9.

Functional Connectivity in the Emotional Processing Regions: Post-hoc tests



Note: A) Mindfulness and Control > EVE: bilateral amygdala seeds and right central opercular cortex; B) EVE and Mindfulness > Control: bilateral thalamus seeds and bilateral frontal pole; C) EVE pre-intervention > post-intervention: bilateral hippocampus seeds and left postcentral gyrus.

See Table 3 for all statistical results.

Table 3.

Functional Connectivity Results

Contrast	Brain Regions	MNI Coordinates	T-score	p-value
	Default mode network			
EVE group Post>Pre	mPFC seed and left paracingulate gyrus	-10, 48, 12	5.45	0.006
	mPFC seed and right thalamus	20, -18, 8	4.75	0.009
Mindfulness group Post>Pre	mPFC seed and right thalamus	20, -18, 8	4.10	0.007
EVE group Pre>post	mPFC seed and left middle temporal gyrus	-70, -24, -6	-4.45	0.012
	Bilateral LP seeds and left postcentral gyrus	-42, -40, 48;	-6.45	0.024
	Bilateral LP seeds and right postcentral gyrus	38, -30, 48	-4.71	0.028
Mindfulness group Pre>Post	mPFC seed and left middle temporal gyrus	-70, -24, -6	-4.59	0.003
Control group Pre>post	mPFC seed and left middle temporal gyrus	-70, -24, -6	-3.11	0.036
EVE<Mindfulness pre and post	PCC seed and right occipital pole	6, -88, 38	-4.98	0.009
EVE<Control pre and post	PCC seed and right occipital pole	6, -88, 38	6.07	0.001
	Salience network			
EVE group Post>Pre	Bilateral insula seeds and left inferior temporal gyrus	-54, -54, -26	11.54	0.001
	Frontoparietal network			
EVE group Pre>Post	Bilateral lPFC seeds and right middle frontal gyrus	44, 36, 38	-8.90	0.002

	Bilateral lPFC seeds and right postcentral gyrus	44, -30, 58	-8.62	0.002
	Emotional Processing Regions			
EVE<Mindfulness pre and post	Bilateral amygdala seeds and right central opercular cortex	34, -10, 16	-7.82	<0.001
EVE<Control pre and post	Bilateral amygdala seeds and right central opercular cortex	34, -10, 16	-7.84	<0.001
EVE>Control pre and post	Bilateral thalamus seeds and left frontal pole	12, 58, 26	5.07	< 0.001
	Bilateral thalamus seeds and right frontal pole	12, 64, 30	5.97	< 0.001
Mindfulness>Control pre and post	Bilateral thalamus seeds and left frontal pole	-12, 58, 26	4.20	<0.001
	Bilateral thalamus seeds and right frontal pole	12, 64, 30	4.17	<0.001
EVE group Pre>Post	Bilateral hippocampus seeds and left postcentral gyrus	-32, -26, 46	-10.23	0.003

Note: The *p*-values were Bonferroni corrected for multiple comparisons.

Discussion

The present study examined the resting state functional connectivity (rsFC) of musicians with music performance anxiety (MPA) pre- and post- traditional mindfulness and mindfulness-based vocal improvisation interventions. Specifically, we examined rsFC in regions of the default mode network (DMN), salience network (SN), frontoparietal network (CEN), and in various emotional processing regions. It was hypothesized that following both mindfulness-based programs, musicians would show increased rsFC between DMN, SN, and CEN regions from pre- to post-intervention, while those in the control group would show no such changes. Differences in rsFC were found between the Mindfulness, EVE, and Control groups between various regions of these networks and in other brain regions outside these networks. The most notable differences in rsFC from pre- to post-intervention were found among the EVE group, specifically between DMN regions, between regions of the DMN and SN, and between regions of the DMN and brain regions related to emotional processing. This study will add to the limited literature on the neurobiological effects of mindfulness and mindfulness-based vocal practices on MPA among young musicians. Despite the significant results, caution should be taken due to the small sample size of the study.

Default Mode Network

Through strategies learned in the EVE and Mindfulness practices, participants may have improved their control over negative self-referential attributions and self-critical mind-wanderings. Specifically, these practices could have strengthened participants' ability to modulate their attentional resources, directing awareness towards certain aspects of the present moment and away from rumination. These effects appear to be strongest in the EVE group.

Following EVE, rsFC increased between the medial prefrontal cortex (mPFC) and the left paracingulate gyrus. The EVE group's enhanced communication between the DMN (mPFC) and SN regions (paracingulate gyrus) is consistent with previous findings showing that mindfulness can augment communication between the SN and DMN (Rahrig et al., 2022), thus enhancing attentional and affective processing. Considering that the mPFC is involved in self-referential processing (Jenkins & Mitchell, 2011) and that the paracingulate gyrus is involved in attentional resource allocation during divided attention (Gennari, Millman, Hymers, and Mattys, 2018), participants may have been better able to use this SN region to modulate mind-wandering about personal attributions after EVE. Specifically, participants may have improved their ability to direct attention away from rumination and allocate more attention to aspects of the present moment.

Attentional modulation may also have been influenced by EVE and Mindfulness, considering that both groups showed increased rsFC between the mPFC and the right thalamus from pre- to post-intervention. Through its functional interaction with the DMN and ascending reticular activating system, the thalamus can balance self-referential processing, which the mPFC plays a crucial role in (Jenkins & Mitchell, 2011). The mPFC also plays a role in awareness and vigilance of the present moment, which the ascending reticular activating system facilitates (Maldonato, 2014; Wang, Xu, Song, Li, Zhen, Yang, and Liu, 2014: 297). This pattern of rsFC may indicate that, following both traditional and vocal-based mindfulness practices, the thalamus was acting as a switch between brain states of mind-wandering and mindful awareness of the present moment. Furthermore, a large body of evidence suggests that the thalamus is a key generator of the alpha rhythm (8-12 Hz), a frequency of brain activity that occurs during mind-wandering and can modulate the connectivity in the DMN (Hughes & Crunelli, 2005). Participants in both programs may have more effectively modulated their self-referential processing, carried out by the DMN, through enhanced thalamic input when experiencing negative thought patterns or rumination.

The EVE intervention may have had a particular impact on self-referential processing. Participants in the EVE group showed a decrease in rsFC between the bilateral lateral parietal lobe (LP) seeds within the DMN and the bilateral postcentral gyrus (a region outside of the networks noted in our hypotheses) from pre- to post-intervention. The somatosensory cortex within the postcentral gyrus plays a role in emotion regulation strategies (Kropf, Syan, Minuzzi, and Frey, 2018), and the LP within the DMN is involved in self-referential thought. This decrease in rsFC may reflect a weaker connection between self-referential thought and emotion regulation. Specifically, EVE participants may have relied less heavily on emotion regulation techniques post-intervention during self-referential thought; this may represent the weakening of ruminative thoughts following EVE. These modulations of the EVE group's DMN activity from pre- to post-intervention are consistent with the EVE discussion transcript themes of top-down present moment awareness and increased confidence (Boland et al., 2025).

Across both time points, there was also a pattern of rsFC with respect to the DMN that was specific to the EVE group. Compared to the Mindfulness and Control groups, the EVE group showed lower rsFC between the PCC and right occipital pole at both time points, possibly reflecting differences in the groups' coupling of visual processing and DMN activity (Geffen Smallwood, Finke, Olbrich, Sjoerds, and Schlagenhauf, 2022). This effect may have arisen from a lack of randomization for each group. For example, external factors such as sex and trait mindfulness might have driven these group differences. Six out of the seven EVE participants were female, while the other two groups had even sex distributions. These sex differences between groups may have particularly influenced our findings pertaining to the PCC seed of the DMN, considering that males and females have shown significant differences in DMN connectivity (Ryali, Zhang, de Los Angeles, Supekar, and Menon, 2024); specifically, the PCC showed consistent differences between sexes (Ryali et al., 2024: 6). The observed pattern of rsFC suggests that EVE participants were less likely than the other groups to exhibit mind-wandering involving visual stimuli (Geffen et al., 2022; for example, visual stimuli tied to autobiographical memory retrieval and imagining the future), perhaps indicating higher levels of pre-existing mindfulness than the other groups. Future studies should include a measure of baseline trait mindfulness. They should also employ a randomized design to better tease apart effects of group and time, reducing potential variability from external factors.

There was also a change in rsFC from pre- to post-intervention shown by all groups. All three groups showed a decrease in rsFC between the mPFC and left middle temporal gyrus. The posterior middle temporal gyrus was suggested by Davey, Thompson, Hallam, Karapanagiotidis, Murphy, De Caso, Krieger-Redwood, Bernhardt, Smallwood, and Jefferies (2016) to play a key role in goal-oriented cognition within the DMN. This effect may have arisen from increased familiarity with the MRI scanner from the first to second session, with participants requiring less goal-oriented cognition or effort to regulate thought patterns and adjust to the scanner due to having completed the process previously.

Salience Network

From pre- to post-intervention, the EVE group may have become more attuned to their internal sensations. This potential change was reflected by their increase in rsFC between the bilateral insula, an SN region involved in detecting relevant stimuli, including bodily sensations (Hasenkamp et al., 2012; Hölzel et al., 2011), and the left inferior temporal gyrus, a region associated with various aspects of mindfulness (Pickut, Van Hecke, Kerckhofs, Mariën, Vanneste, Cras, and Parizel, 2013).

The temporal lobe has been implicated in deep stages of meditation (Piron, 2003), which can involve strong feelings of pleasure. Hölzel, Ott, Gard, Hempel, Weygandt, Morgen, and Vaitl (2008) found that experienced meditators showed increased grey matter volume in the inferior temporal gyrus, with total hours of meditation practice showing positive associations with grey matter volume in this region. The inferior temporal gyrus may be a temporal region that is particularly malleable to the long-term effects of mindfulness practice, and based on the present study's findings, it could be altered by mindfulness-based interventions in as little as two weeks.

Hölzel and colleagues (2008) also found increased grey matter concentration in the right insula among meditators, which was suggested to be due to heightened awareness of bodily sensations. The EVE group's increased connection between the insula and left inferior temporal gyrus may have arisen from improved awareness of bodily sensations in the present moment as well as pleasure in noticing such sensations, both of which were components of EVE. These findings are consistent with various themes evoked during EVE, including body, breath, and voice awareness as well as pleasure (for example, confidence and playfulness in exploring internal and external sensations; Boland et al., 2025).

Frontoparietal Network

Awareness of both internal (for example, body, voice, and breath) and external (for example, community and environment) aspects of the present moment may have enabled the EVE group to develop increased attentional efficiency from pre- to post-intervention, which was reflected by their decreased rsFC between the lateral prefrontal cortex (lPFC) and both the right middle frontal gyrus and the right postcentral gyrus. The right middle frontal gyrus has been proposed as a site of convergence between the dorsal and ventral attention networks, interrupting ongoing endogenous attentional processes in the dorsal network and reorienting attention to exogenous stimuli (Vossel, Geng, and Fink, 2013). It also reorients attention from exogenous to endogenous stimuli (Japee, Holiday, Satyshur, Mukai, and Ungerleider 2015; Wang, Ma, Wang, Ding, Men, Tan, Gao, Qin, He, Dong, and Tao, 2025). Through the multifaceted present-moment awareness taught in EVE (i.e., awareness of and engagement with the voice, body, breath, and environment), the EVE group may have depended less on the right middle frontal gyrus to direct attention away from mind-wandering and toward the present moment during resting state. This strengthening of attentional resources is consistent with our previous finding that, compared to the Mindfulness and Control groups, the EVE group showed less activity in brain regions devoted to cognitive processing during a working memory task post-intervention (for example, middle cingulate gyrus), reflecting enhanced neural efficiency (Boland et al., 2025).

Considering that the use of emotion regulation strategies activates the somatosensory cortex (within the postcentral gyrus; Kropf et al., 2018), the post-EVE decrease in rsFC between the LPFC and postcentral gyrus may also reflect that less emotional regulation was required during potentially ruminative thought patterns. This decrease in rsFC may also reflect that, following EVE, less energy and attention was required to process and integrate perceptual information that arose during mind-wandering, considering that perceptual processing is another key function of the postcentral gyrus (Chen, Gong, Wang, Xu, Zhong, Peng, Song, Xu, Lian, Shao, and Weng, 2023). These effects may be explained by the present-moment focus of EVE as well as the overall somatic focus of mindfulness practices (Kerr, Sacchet, Lazar, Moore, and Jones, 2013). The vocal focus of EVE as well as its emphasis on engaging with (rather than simply noticing) external and internal aspects of the present moment likely trained participants in top-down attentional control; such attentional training may have reduced their reliance on connections between the frontoparietal network and the postcentral gyrus to regulate emotions.

Emotional Processing Regions

Not only is it possible that EVE participants could better modulate self-referential processing post-intervention, but they may also have experienced a decrease in such processing altogether, specifically in terms of emotional arousal. The EVE group showed significantly less rsFC between the bilateral hippocampus and the left postcentral gyrus from pre- to post-intervention. The decrease in the hippocampus' connection with the postcentral gyrus may signal lower levels of rumination and higher present-moment awareness.

On a functional level, when processing varieties of compassion towards others' mental and physical circumstances (for example, social, psychological, or physical pain), fMRI results from Immordino-Yang & Singh (2011) showed that connectivity increased between bilateral hippocampi and cortical systems (for example, temporal, prefrontal, and cingulate areas) involved in visceral somatosensation, emotional feeling, social cognitive, and self-related processing. Considering that the postcentral gyrus plays a role in both somatosensation and self-referential processing (Chen et al., 2023; Northoff, Heinzel, de Greck, Bermpohl, Dobrowolny, and Panksepp, 2006), EVE participants' decreased rsFC between the hippocampus and postcentral gyrus suggest less processing of emotional arousal (for example, anxiety). This decrease in rsFC may have arisen from the somatic stimulation involved in EVE's vocal exercises, consistent with EVE themes of bottom-up and top-down body and breath awareness as well as tangible sensory feedback (Boland et al., 2025). Somatic stimulation during mindfulness practices was shown by Kerr et al. (2013) to help regulate the mind when it wanders from its somatic focus. Specifically, Kerr and colleagues' computational model predicted mindfulness practices to enhance top-down regulation of alpha activity in the primary somatosensory cortex. This enhanced regulation of mind-wandering was suggested to be a key part of initial stages of mindfulness training, which may provide a foundation for enhanced cognitive regulation and metacognition. Our findings offer further support for the benefits of the brief EVE intervention among musicians who do not have mindfulness experience.

At both time points, the EVE group showed lower rsFC between the bilateral amygdala and right central opercular cortex than the mindfulness and control groups. Compared to the control group, the EVE and Mindfulness groups also showed greater rsFC between the bilateral thalamus and bilateral frontal pole at both time points. The lack of randomization in the allocation of participants to the three groups may, again, have accounted for these findings. Considering that the opercular cortex is adjacent to the insula (Mălîia, Donos, Barborica, Popa, Ciurea, Cinatti, and Mîndruţă, 2018), a key node of the salience network, this pattern of connectivity may reflect rsFC between emotional processing regions and the salience network. The EVE and Mindfulness groups' increased rsFC between the bilateral thalamus and frontal pole may reflect heightened attentional engagement with the present moment, both pre- and post-intervention. The projection from the medial subregion of the frontal pole to the thalamus is central to attentional control within the DMN (Alves, Foulon, Karolis, Bzdok, Margulies, Volle, and Thiebaut de Schotten, 2019; Penner, Osuch, Schaefer, Théberge, Neufeld, Menon, Rajakumar, Bourne, and Williamson 2018; Snelleksz, Rossell, Gibbons, Nithianantharajah, and Dean, 2022). These group differences in rsFC across both time points may reflect external factors affecting the groups' connections between certain emotional processing regions and the SN and DMN.

Overall, the changes observed between groups and time points, specifically among the EVE group from pre- to post-intervention, indicate that mindfulness-based vocal improvisation may help improve attentional control and reduce negative thought patterns among musicians with MPA. Such changes in resting brain activity could translate well to the context of music practice and performance. Specifically, the musicians' engagement with several aspects of the present moment in EVE (rather than only paying attention to them, which is common in traditional mindfulness) appeared to strengthen EVE participants' attentional resources. This attentional modulation could enable them to more efficiently direct attention towards the executively demanding task at hand (for example, playing a musical piece) and away from negative thoughts (for example, concern about making a mistake). The vagus nerve stimulation involved in EVE may also explain why, compared to the Mindfulness group, the EVE group showed more rsFC alterations indicating reduced anxiety from pre- to post-intervention (Yuen & Sander, 2017).

Strengths, limitations, and future directions

The present study revealed the impact of both traditional mindfulness and EVE on the brain activity of musicians with MPA while not engaged in any given task. This study had various strengths, one of which is the inclusion of traditional mindfulness as an active control condition to compare with the novel EVE intervention. Its longitudinal design also added to the reliability of our findings, especially considering that two weeks of such interventions has been shown to produce beneficial effects on anxiety (Berghoff, Wheeless, Ritzert, Wooley, and Forsyth, 2017). The two-week duration of these interventions makes them more accessible to people with MPA than longer, more intensive interventions. This study also adds to the limited number of longitudinal studies on the neurobiological influences of mindfulness interventions on MPA.

There are also several limitations to this study, the first of which is the small sample size, especially for the EVE group. It is also important to note that the sex distribution in the EVE group was uneven, with only one male and six females. Given the promising results but preliminary nature of this work, large-scale studies on EVE and MPA should be conducted. Furthermore, despite females showing higher MPA than males (Iusca & Dafinoiu, 2012) and possibly benefiting more strongly from EVE and mindfulness than males, it is important that future large-scale studies have an even sex distribution to control for this variable.

A further limitation is that certain group effects may have arisen from a lack of randomization. Specifically, caution should be exercised when interpreting our findings, considering that factors such as age, sex, and motivation to partake in mindfulness or EVE may impact both pre- and post-intervention brain activity. Future studies on this topic should ensure that participants are randomly assigned to experimental and both active and passive control conditions.

Furthermore, future work on this topic should compare musicians with MPA to the general public and people in other performance-intensive professions, to increase precision in finding what interventions work best for musicians with MPA relative to other groups of people, and how such interventions may differentially impact resting state brain activity. Future studies should also examine the effects of EVE and mindfulness on MPA in participants of various age groups to increase our knowledge of how such effects manifest across the lifespan. Finally, future studies should investigate the replicability of the EVE protocol to see if EVE sessions conducted by other music therapists trained on this protocol (other than the music therapist who developed the intervention) have the same effects as those shown in the present study.

Conclusion

Two weeks of the mindfulness-based vocal improvisation practice, EVE, may exceed the impacts of traditional mindfulness in decreasing anxiety and increasing present moment focus among musicians with MPA. Through alterations in neural networks devoted to attentional control (Default Mode, Salience, and Frontoparietal Networks) as well as emotional regulation (brain regions including the thalamus, amygdala, and hippocampus), EVE may enhance musicians' ability to focus on the present moment in a non-judgmental manner. Such focus could ultimately improve their ability to manage the executive demands of musical performance. EVE is an accessible, cost-effective intervention that could be highly beneficial to implement into the lives of musicians experiencing MPA. As we learn about the powerful impact of music on our wellbeing, it is important to grow our understanding of musicians' thoughts and feelings to ensure that they enjoy creating it.

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CHAPTER FOUR: The neural impact of Body Mapping Education for musicians with performance anxiety

Boland, A.K., Johnson, J., Stanson, N., Comeau, G., Dagenais, M., Bakker, E.G., Roy, O., Housni, N., Smith, A.M. (Under Review) The neural impact of Body Mapping Education for musicians with performance anxiety. *Scandinavian Journal of Psychology*.

Abstract

Music performance anxiety (MPA) negatively affects musicians' personal and professional lives. Musicians suffering from MPA also frequently report excessive muscular tension and injuries. This study investigates the neurophysiological impacts of a three-week-long Body Mapping for Musicians (BMM) intervention among 23 professional musicians with MPA, aged 17-66. The intervention involved a formal full day course, a one-hour group exploration session, and three weeks of self-directed practice. Pre- and post-intervention, we investigated brain activity with fMRI during an anxiety-provoking task and a working memory task, including error and reaction time data. We assessed subjective anxiety, trait mindfulness, and musculoskeletal discomfort with questionnaires. Themes from participant discussions during group exploration BMM sessions were also assessed. During the anxiety-provoking task, blood flow in brain regions involved in emotional processing and rumination decreased from pre- to post-intervention. During the working memory task, blood flow in brain regions involved in sensorimotor integration increased post-intervention, as did accuracy on the task. State, trait, and performance anxiety decreased post-intervention. Participants also reported lower anxiety after the anxiety-provoking task. Themes of freedom in movement, breath, and awareness emerged in group exploration BMM sessions. Preliminary neuroscientific findings suggest that BMM may reduce MPA, through enhanced sensorimotor processing and nonjudgmental awareness.

Keywords: Body Mapping for Musicians, Music Performance Anxiety, mindfulness, neuroimaging, fMRI, mixed methods

Introduction

The majority of musicians will suffer from an injury during their careers, and misuse of the body while playing/singing is a primary contributor to such injuries (Bindel, 2013). Music Performance Anxiety (MPA) may be a primary risk factor for these playing-related injuries, as it involves intense apprehension toward music performance (Kenny, 2011). This can lead to the overuse and strain of muscles during repetitive practice (due to concern for making mistakes) as well as breathing difficulties (due to anxiety symptoms; Passarotto and colleagues, 2023; Sokoli and colleagues, 2022). As musicians move their bodies for a living, somatic approaches to music pedagogy are important for helping musicians learn to move in a healthy way (Bindel, 2013). Body Mapping for Musicians (BMM) is a somatic approach that effectively fulfills this need by providing musicians with accurate information on the body's anatomy as well as opportunities to practice healthy ways of moving (Buchanan, 2005; Conable, 1998; Holt, 2016). Drawing from principles of somatic education and mindfulness, BMM employs movement training, anatomical education, and mindfulness-type practices on breath, body, and movement awareness for enhancing musicians' physical and mental well-being (Buchanan, 2005; Conable, 1998). By addressing both mental and physical challenges among musicians, BMM may be a promising approach that could produce lasting impacts on musicians' health.

The course What Every Musician Needs to Know About the Body (WEM) offered by The Association for Body Mapping Education (ABME), founded by Barbara Conable in 1997, helps musicians address their mismappings (i.e., incorrect understandings of how the body works; Conable, 1998) through remapping exercises, notably examining anatomy through images, movement practice, drawing, and practicing mindful body awareness; it also encourages self-directed practice outside of classes (Barrett, 2006). BMM education from this course has been shown to improve playing, physical symptoms, knowledge of body movement, body awareness, and subjective perceptions of performance quality among various instrumentalists (Bindel, 2013; Buchanan, 2005; Holt, 2016; Knaub, 1999; Rader, 2023; Ross, 2022; Slade and colleagues, 2020). However, the impact of BMM on MPA warrants investigation.

The mental and physical effects of MPA can lead to debilitating outcomes for musicians' professional and personal lives, including substance use and career abandonment (Kenny, 2011; Orejudo Hernández and colleagues, 2018). It can also have negative cognitive effects, such as impairing working memory (Popean, 2019), a crucial skill for music performance; notably, musicians are guided by musical memory (where parts of a piece must unfold in their mind before it can be played), and must hold notes in mind as preparation for when they are to be played (Rayner & Pollatsek, 1997; Sloboda, 1974, Sloboda, 1978). While music is an important and rich part of our lives, the pressure that musicians face to constantly practice and perform at a high level can lead to mental and physical health issues, impeding their ability to create and enjoy making music. Such effects can lead to chronic stress among other negative long-term outcomes (Cardoso and colleagues, 2025). There is thus a need for interventions aimed at improving musicians' well-being as they practice and perform, with the goal to foster long-term health and well-being among musicians.

BMM may counter the effects of MPA by enhancing body awareness (Rader, 2023; Salonen, 2018), knowledge of body movement (Buchanan & Hays, 2014; Rader, 2023; Ross, 2022), and subjective perceptions of performance quality (Buchanan & Hays, 2014; Reyneke and colleagues, 2024). However, further empirical findings are needed to understand how BMM may impact musicians' health and well-being (Buchanan & Hays, 2014; Slade and colleagues, 2020) and to lend credence to the effectiveness of the techniques. BMM should thus be investigated on a neuroscientific level, to reveal the objective mechanisms of its effects.

BMM involves processes of retraining attentional focus, body awareness, and movement, through techniques such as kinesthetic awareness practice and anatomical education. While there exists no neuroscientific research on BMM to date, the neural correlates underlying BMM processes must be considered. BMM may play an important role in reducing MPA through improved regulation of emotions, attention, and movement. BMM may improve musicians' emotion regulation by teaching proper use of the body while performing and increasing musicians' confidence (Buchanan & Hays, 2014), perhaps permitting positive reappraisal of the performance experience. BMM also trains one's inclusive awareness, which refers to simultaneous attention toward bodily sensations and the external environment during performance, and can reduce anxiety (Buchanan & Hays, 2014). This intervention may thus alter musicians' neural activity in regions involved in attentional and emotional control, as has been observed in mindfulness-based interventions (Boileau, 2024; Boland and colleagues, 2025a; Boland and colleagues, 2025b). Furthermore, BMM can influence internal representations of the body and may thus change the activation patterns of motor and proprioceptive brain regions (e.g., Facer-Childs and colleagues, 2021; Ferri and colleagues, 2012; Marvel and colleagues, 2019); such neural alterations may reflect more adaptive motor planning, coordination, and internal representations.

With the rising interest and use of somatic education for improving musicians' mental and physical health, there is currently a need for neuroscientific evidence of the effects of such interventions on musicians' health, well-being, and MPA, specifically through research that employs a repeated-measures design (Buchanan & Hays, 2014; Chow & Mercado, 2020). Furthermore, the majority of existing research has focused on student musicians (e.g., Buchanan & Hays, 2014), while there is a gap in our knowledge of how BMM can impact professional musicians, who are in significant need of such techniques as they play music for their careers. Self-regulated learning of BMM techniques also warrants further research as an accessible and individualized supplement to activities that take place during formal BMM course sessions (Buchanan & Hays, 2014). Furthermore, BMM uses mindfulness-based techniques that warrant further investigation in the context of MPA. Mindfulness has been shown to help reduce MPA (e.g., Boileau and colleagues, 2024; Boland and colleagues, 2025a; Boland and colleagues, 2025b) and BMM may amplify these effects through its focus on body, breath, and movement.

This mixed methods study sought to address the above-mentioned needs, using brain imaging, self-report questionnaires and qualitative analyses in a group of professional musicians participating in a WEM BMM course. This is the first study to investigate both the neural underpinnings and the subjective effects of Body Mapping education in professional musicians. The WEM BMM course consisted of two in-person sessions, followed by three weeks of self-directed learning and application of the BMM principles. Before and after the intervention, brain activity was recorded using fMRI during an anxiety-provoking task and a working memory task. Participants' self-reported anxiety levels after the anxiety-provoking fMRI task were measured, as were reaction time and errors during the working memory fMRI task. In addition, we examined the effects of BMM on questionnaire scores that assessed state anxiety levels, MPA levels, trait mindfulness levels, and musculoskeletal discomfort. Finally, participants' discussion transcripts from group exploration BMM sessions (including discussions about participants' individual experiences learning about and engaging with BMM techniques) were thematically analyzed, with the goal to map subjective experiences onto our quantitative findings.

It was hypothesized that following the intervention, participants would show changes in brain activity in regions involved in attentional regulation, motor control, and proprioceptive awareness during the fMRI tasks. It was also expected that there would be less activity in regions involved in arousal and anxiety during the anxiety-provoking task. Additionally, working memory performance and mindfulness scores were expected to increase post-intervention, and state anxiety and musculoskeletal discomfort scores were expected to decrease.

Methods

Participants

Twenty-three adult professional musicians, who play music as part of (or entirely for) their career, and answered *yes* to the question "Do you currently experience music performance anxiety?" were recruited. We also included participants who answered yes to the question "Have you ever experienced music performance anxiety in the past?" These individuals all sought to address MPA-related challenges, but had found, for example, that orchestral performances were more stressful than solo performances (and vice versa) and had varying levels of anxiety during different periods of their lives depending on this context.

Participants were aged 17 to 66 (M = 42.2, SD = 15), with 17 identifying as women and 6 as men. This number of participants allowed sufficient power to detect a medium effect for analyses described in the *Data Analysis* section. Participants were recruited from local orchestras and professional musician organizations. Students at local Music Schools who freelance as musicians were also recruited. We recruited participants who play a wide range of instruments, to promote generalizability of our findings to as many musicians as possible. Fourteen different instruments were played by participants. The instruments participants chose as their primary instrument to play throughout the study were the following: violin (n = 3), cello (n = 4), viola (n = 1), double bass (n = 1), guitar (n = 1), harpsichord (n = 1), harp (n = 1), piano (n = 4), euphonium (n = 1), French horn (n = 1), trumpet (n = 1), vocals (n = 1), alto saxophone (n = 1), flute (n = 2).

Participants were recruited in two cohorts, to allow small enough class sizes for the two BMM workshops. Data were collected from the first cohort (9 participants) from August to October 2025, and from the second cohort (14 participants) between October and December 2025. Exclusion criteria included having ever taken a formal BMM course, being under 17 years of age, visual and/or hearing problems, having previously engaged in any kind of formal mindfulness training, past or present substance use disorders, past loss of consciousness for over ten minutes other than during surgery, non-removable metal or implanted devices in the body, current pregnancy or breastfeeding, back problems, or claustrophobia. See *Table 1* for demographic information.

Table 1. Participant Demographic Information.

% Right-handed	**% Currently Students**	**% Take part in physical activity**	**% Have experienced a playing-related injury**	**Age of commencing studying their instrument (M, SD)**	**Age of commencing professional playing (M, SD)**	**Average performance anxiety level (on a 10-point scale) during their last five performances (M, SD)**
83% (19/23)	17% (4/23)	78% (18/23)	87% (20/23)	8.88 years (SD = 4.07)	20.57 years (SD = 8.48)	6.65/10 (SD = 1.23)

Note: This table represents participant demographic information on handedness, current student status, physical activity, previous playing-related injuries, age of commencing studying their instrument, age of commencing professional playing, and average performance anxiety during their last five performances. Participants' previous injuries were wide-ranging and included the following: wrist pain, left arm and shoulder pain and tension, neck strain, back discomfort, finger swelling, nerves trapped in the neck and spine, pain from tension or weakness associated with holding the instrument, pain in shoulders, jaw tension, breathing tension, tenosynovitis, tingling in hands, bow arm upper bicipital tendonitis, rotator cuff weakness, thumb fatigue and pain, arm and shoulder tension, general vocal stress, breathing difficulties, tendonitis, pain between shoulder blades while playing, ulnar tunnel syndrome, arm muscle strain/tightness, jaw tightness, wrist strain, repetitive strain injury in forearm, wrist, and elbow, neck, left trapezius pain, left upper arm pain (forearm, wrist, fingers), right deltoid pain, wrist tingle, and sore clavicle.

Procedure

Baseline Measurements: Questionnaires and Performance Session

Participants came to a university research laboratory **[masked for peer review]** for the first study session. This laboratory is a state-of-the-art recording studio, with controlled acoustics and reduced background sound levels. Participants completed the revised Kenny Music Performance Anxiety Inventory (KMPAI), the trait and state anxiety subscales of the Spielberger Stat-Trait Anxiety Inventory (STAI), the Mindfulness for Musicians Questionnaire (MfM), and the Mindful Attention Awareness Scale (MAAS) (on a computer, via Qualtrics), along with the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) on paper (for ease).

Demographic and Health Questionnaire. A demographic and health questionnaire was administered along with the consent form prior to the first in-person study session, which included participants' gender, hand preferences for various activities, physical activity level, history of injury, and level of anxiety during their past five performances. Questions also assessed participants' music background, including the instruments they play, the age they started formal music training, their highest music degree training, as well as the age at which they commenced professional playing.

Kenny Music Performance Anxiety Inventory (KMPAI) – Revised. Participants completed the KMPAI (Kenny, 2009) to assess their levels of music performance anxiety. The revised KMPAI contains 40 items within eight domains of performance anxiety: Somatic Anxiety/Worry about Performance, Worry Focused on Self/Other Scrutiny, Depression/Hopelessness, Parental Empathy, Memory, Trait Anxiety, Anxious Apprehension, and Biological Vulnerability. Scores are expressed as percentages. Higher domain-specific and total scores indicate higher MPA. Analysis of this questionnaire focused on the total score, and the first two domains. These domains were chosen based on their relevance to the performance context of this project as well as their emphasis on more dynamic traits. In scoring the KMPAI, the factor structure from Kenny (2009, 2011) was used.

Spielberger State-Trait Anxiety Inventory (STAI). The State-Trait Anxiety Inventory (STAI; Spielberger, 1983) was also administered. The STAI contains two subscales: trait anxiety and state anxiety. The present study used the trait subscale at baseline to assess dispositional (or one's typical levels of) anxiety; this subscale contains 20 questions and uses a 4-point Likert scale, ranging from one (not at all) to four (very much so), including statements such as "I often feel worried." The state subscale, which assesses anxiety in the present moment, also contains 20 questions, with a 4-point Likert scale; the state subscale was used at several points in the study, for participants to rate the extent to which a given statement resonates with their feeling in the present moment. State subscale items include statements such as "I feel at ease" and "I feel strained," on a scale ranging from one (not at all) to four (very much so). After reverse scoring certain items, a total sum score can then be computed, with higher scores indicating higher anxiety.

Mindfulness for Musicians Questionnaire (MfM). The Mindfulness for Musicians (MfM) questionnaire was administered to assess trait mindfulness specific to the musician population of this study. The MfM was developed in response to FFMQ triangulation with interview findings in Czajkowski's (2013) Mindfulness for Singers pilot study. In this study, a mindfulness questionnaire for musicians was developed to investigate the experiences of student musicians completing mindfulness interventions that could be missed by the more general FFMQ. This questionnaire contains 15 items, divided into the domains of Observe, Act with Awareness, Describe, Non-Judge, and Non-React. The 15 items on the questionnaire were also divided into three music-making contexts: music lessons, music practice, and performance, as these were the contexts in which mindfulness showed particular effects on singers who completed the pilot study. Items are in the form of statements, to be responded to using a 5-point scale ranging from 1 (never or very rarely true) to 5 (very often or always true), with a total score range of between 15 and 75; reverse scoring is applied to negatively worded items. An example item is "I can easily describe to others the physical sensations or emotions I feel when I sing or play my instrument."

Mindful Attention Awareness Scale (MAAS). The Mindful Attention Awareness Scale (MAAS) was administered as a second tool to assess trait mindfulness that is not specific to the music-making experience. The MAAS was developed by Brown & Ryan (2003). It contains 15 items on trait mindfulness in everyday experiences in the form of statements related to present moment awareness. The items are scored on a six-point Likert scale ranging from "almost always" to "almost never." An example item is "I find it difficult to stay focused on what's happening in the present."

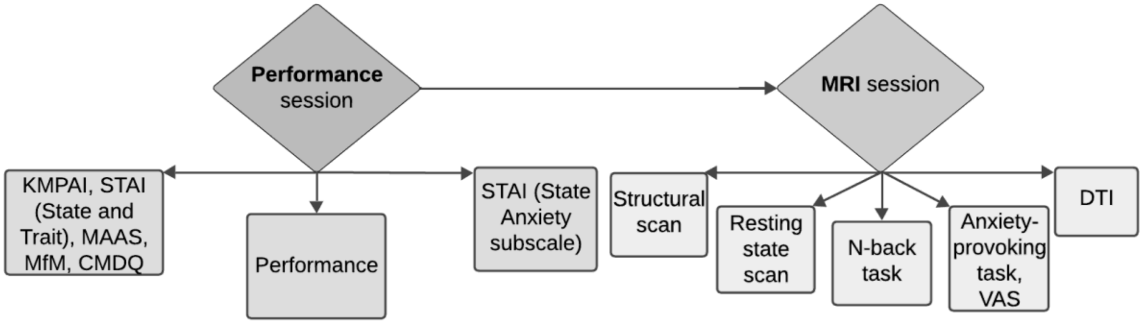
Cornell Musculoskeletal Discomfort Questionnaire (CMDQ). The Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) was administered to assess participants' levels of pain and musculoskeletal discomfort to target playing-related injuries or discomfort specific to each participant. The CMDQ was originally created to assess the musculoskeletal concerns of office workers. However, the hand and body diagrams in the questionnaires are suitable for musicians (Hedge and colleagues, 1999a; Hedge and colleagues, 1999b); for example, it was employed in Rader's (2023) investigation of the physical effects of BMM among musicians. In the body scale, a diagram of a standing male is presented; this version was chosen considering that it is commonly used and could reflect the body of any participant of any gender. The left- and right-hand scales were also used. For each area of the body or hand, participants answered Likert-type scales indicating the frequency of discomfort, level of discomfort, and amount of interference the discomfort caused to their work within the last work week. The frequency column ranges from "Never" (0) to "Several times every day" (10). The column indicating level of pain or discomfort ranges from "None" (1) to "Very uncomfortable" (4). Level of interference from the discomfort ranges from "Not at all" (1) to "Substantially interfered" (3). Multiple possible scoring techniques exist for this scale. For this study, scoring was conducted by multiplying the frequency score for each type of musculoskeletal discomfort by the discomfort score by the Interference score; this allows for the creation of a composite score for that area of the hand or body. The highest possible composite score for the entire questionnaire is 2,880.

Performance Procedure. Following completion of all questionnaires, participants had 5-7 minutes to warm up with their instruments in the same room where they completed the questionnaires. Researchers were not in sight of participants as they warmed up. Participants then performed in front of a panel of two judges in a separate room next door. They performed 5–10 minutes of solo repertoire that they had performed publicly in front of an audience at least once with their instrument of choice, in front of the mock jury panel. The mock jury panel consisted of research staff, who were given the standardized instructions to maintain a neutral expression during the performance, appear to be writing notes down during it, and refrain from interacting with the participants. Prior to entering the performance space, participants were reminded that the jury panel would evaluate their performances and to refrain from interacting with the jury panel (to control for interactions influencing outcome measures). The same judges were present at both pre- and post-intervention performance sessions for every participant. Each performance was video-recorded for use in the anxiety-provoking fMRI task. To control for brain activity within visual cortex regions while participants watched their videos in the scanner, the judges wore the same clothes for every performance session (both pre- and post-intervention), and the background that participants performed in front of was the same for every session. After the performance, participants completed the state subscale of the STAI again.

Baseline Measurements: fMRI Session

Within approximately one week (M = 4.04 days) of this initial performance session, participants underwent a one-hour MRI scan at **[masked for peer review]**. This scan included a high-resolution structural scan, a resting state fMRI scan, a working memory letter N-back task, an anxiety-provoking task, and a Diffusion Tensor Imaging (DTI) scan (tasks are described below). Only the task fMRI data are presented in this manuscript. Right after the anxiety provoking task was complete, a Visual Analog Scale for level of anxiety was administered to measure how calm or anxious participants felt after seeing their own videos versus another musician's control video (adapted from Cella & Perry, 1986). The scale contained a straight line, where one end had a value of one (extremely relaxed), and the other end had a value of 10 (extremely anxious). Participants underwent MRI scans at a 3.0 Tesla Siemens Biograph MR-PET scanner. Participants were asked to lie on the bed of the scanner with their head immobilized in a 32-channel head coil. A T1-weighted spin echo localizer was acquired to confirm positioning and to prescribe the subsequent T1-weighted 3D multi-echo magnetization prepared rapid acquisition gradient echo (MEMPRAGE) sequence (TR = 11.2 ms, TE = 21 ms, flip angle = 60°, FOV = 26 cm, 256x256 matrix, slice thickness = 1.5 mm) for further analyses (van der Kouwe and colleagues, 2008). An echo planar pulse sequence was used for the two fMRI tasks, TR/TE 3000/27 ms, flip angle 90º, FOV 24x24 cm 2, 64x64 matrix, slice thickness 3 mm, 50 axial slices, bandwidth 62.5 kHz. See *Figure 1* for a procedural flowchart.

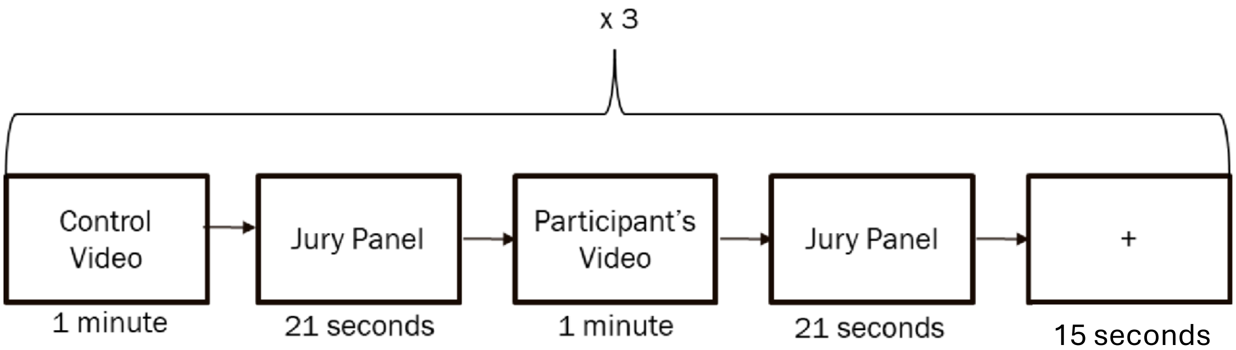
Figure 1. Procedural Timeline.



Note: This flowchart depicts a timeline of testing procedures from the beginning to the end of the study. The flow chart moves from left to right across the page: 1) Administration of the KMPAI, STAI (State and Trait Anxiety Subscales), MfM, MAAs, and CMDQ; 2) Baseline performance; 3) Administration of the State Anxiety subscale of the STAI; 4) Baseline MRI session which encompassed a structural scan, resting state, N-back task, anxiety-provoking task (including the Visual Analogue Scale or VAS), and Diffusion Tensor Imaging (DTI). These procedures were repeated after the BMM intervention period (three weeks).

Anxiety-Provoking Task. Video recordings of participants' pre- and post-intervention performances were played to participants while in the scanner at baseline and post-intervention, respectively, with the goal to evoke feelings of performance anxiety. During the anxiety-provoking task, participants were first shown a video of a young adult female confederate musician playing the cello in the same room as their performance (the control condition – 1 minute); by showing all participants the same control video of this individual playing the cello, we could control for audiovisual input across participants. Participants then saw a video of the mock jury panel from their performance sessions reviewing the performance (21 seconds), followed by their own performance (the anxiety-provoking condition – 1 minute), and finally another video of the jury panel (21 seconds). The sequence was repeated three times and 15 second fixations (cross hair on screen) were presented in between conditions. The first segment of the videos started off at the very beginning of the participant's performance. In each of the three subsequent sequences, the videos began where they left off. For example, after watching 1 minute of the control video in one sequence, the next control video would be a continuation of the first one-minute video (the same applied to the jury and participant performance videos). The same jury panel and control condition confederate were shown to all participants, with the only difference between participants' imaging sequences being the anxiety-provoking condition (i.e., their own videos). In total, the task lasted for eight minutes and 53 seconds. See *Figure 2* for a visual of the task procedure.

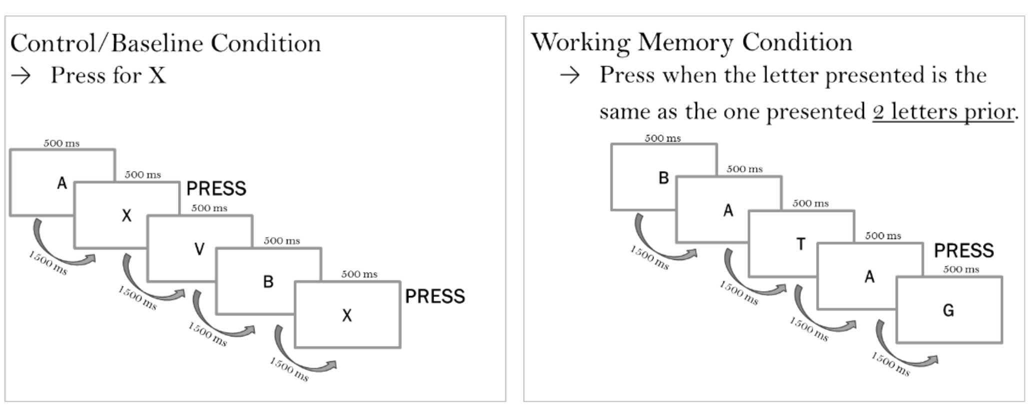
Figure 2. Anxiety Provoking fMRI Task Design.



Note: This flowchart (originally presented in Boland and colleagues, 2025a) depicts the sequence of testing procedures. Box 1 reads "Control Video" (with 1 minute underneath). Box 2: "Jury Panel" (21 seconds underneath). Box 3: "Participant's Video" (1 minute). Box 4: "Jury Panel" (21 seconds). Box 5 contains a fixation cross (15 seconds). There is a bracket above the 5 boxes with x 3 in the center.

Letter N-back Task. One at a time, black letters were presented to participants in the middle of a white screen. Participants were asked to use a fiber optic response pad in the scanner to press a button with their right index finger as quickly and accurately as possible. There were two conditions in the block design. The first was a control or baseline condition where "Press for X" was presented on the screen followed by 16 stimuli (letters of the alphabet) per block; participants were instructed to press the button every time the letter X was presented. The second condition required working memory, where "Press for 2-back" was presented on the screen followed by 16 stimuli (letters of the alphabet except for X) per block; a button press was required when the letter shown was the same as the one presented two letters prior. The stimuli were presented for 500 milliseconds with inter-stimulus intervals of 1500 milliseconds. There were four counterbalanced blocks of each condition (with a total of 128 stimuli). There were rest periods interspersed between blocks for 15 seconds; during these periods, the word "Rest" appeared on the screen. In total, the task lasted for six minutes and 33 seconds. Different letter stimuli and order of stimuli were chosen for the pre- and post-intervention completions of the task, to control for familiarity. See *Figure 3* for a visual of the task procedure.

Figure 3. N-back fMRI Task Design.



Note: These figures (originally presented in Boland and colleagues, 2025a) depict two conditions of the N-back task design. On the left-hand side is the control or baseline condition. Five boxes are shown overlapping, with each box down and to the right a little. In each box is a letter: A, X, V, B and X. The word "press" is written to the side of the boxes with the letter X. On the right-hand side is the working memory condition. The sequence of letters in these 5 boxes is B, A, T, A (with the word "press" to the right), G. For both conditions, each box has 500ms written above and an arrow (with 1500ms written) moving from one box to the next.

Body Mapping for Musicians Intervention

Within two weeks of being scanned, each participant took part in the BMM intervention, carried out by a licensed Body Mapping Educator (and violinist), at the University **[masked for peer review]**. The formal courses were held over two days. Information about the curriculum (written by the licensed Body Mapping Educator) was provided to participants the day before the course, to provide an overview of the course. The first day of the BMM intervention was a seven-hour long group course, which encompassed five sections of the WEM lectures:

Section One (Introduction to Body Mapping). Section One focused on the definition and goals of BMM, with regard to how it helps musicians to retrain their movement, senses, and attention, with the goal of finding more freedom in their music-making. A key focus of this section was on how to address MPA by retraining the quality of attention, paying less exclusive attention to internal ruminations or external surroundings, and paying more inclusive attention to both internal and external sensations at the same time.

Section Two (Six Places of Balance). This section focused on ways of sitting and standing while playing and singing. Specifically, it emphasized ways to minimize muscular work and ensure that musicians' weight is placed on the most balanced places of rest. This targeted MPA by reducing bodily tension and unnecessary muscular effort during playing.

Section Three (Arms). This section focused on identifying and correcting musicians' common mismappings of the arms and the hands, aiming to help musicians find their freest movement when playing. This session outlined ways of addressing and preventing shoulder region pain, tightness, and musical injuries that have detrimental effects on performance, such as tendonitis and carpal tunnel syndrome. Experiencing less pain in the arms and hands may reduce MPA through freer, more confident movement, with less stress and risk of injury.

Section Four (Legs). The importance of musically appropriate leg movement was the focus for this section, with the goal of accurately remapping the legs based on their true design to help support the whole body; this includes the importance of the legs in helping the arms achieve necessary movements during singing and playing. Knee and hip joint pain were addressed in this section as well. This session targeted MPA by promoting support from the legs, which can consequently lead to freer, less strained movement.

Section Five (Breathing). The final interactive section focused on the common mismappings about breathing, which can lead to musicians making unnecessary effort, experiencing limitation, and suffering injury. This session also focused on how effective breathing techniques improve both balanced sitting and mental health.

Group Explorations. The day after the interactive lectures, the group exploration sessions occurred, lasting approximately 1 hour per participant group (of two to three musicians). In these groups, each participant played a scale or fragment of a favourite piece or piece they are working on, then discussed their mismappings with the Body Mapping Educator and shared insights with the other participants to discover new ways of moving during playing or singing. Participants also discussed how they felt when applying BMM techniques to their playing. The discussions focused on participants' experiences implementing BMM techniques. This group exploration provided participants with hands-on skills for incorporating the information taught during interactive lectures into daily practice and performance. These sessions were recorded and transcribed for the purpose of thematic analysis.

Self-directed Practice. Following the two formal course sessions, participants were asked to complete open-ended written reflections on their experience with BMM for three weeks (i.e., reflections could be completed as often as was convenient for participants, e.g., on a daily or weekly basis). The goal of these reflections was to facilitate the implementation of course information into participants' daily lives. Reflections were encrypted and sent securely to researchers via Dropbox in the format of participants' choosing (e.g., document, image) for the purpose of thematic analysis (which will be presented in another paper). Participants were encouraged to pay attention to when they used skills from the course and to record how many times they noticed themselves using such skills. The Body Mapping Educator prompted participants to reflect on the physical and mental changes they experienced post-intervention, and how this may relate to Body Mapping Concepts.

Post-Intervention Measurements

Following the pre-intervention study procedures and the BMM intervention, participants completed the same procedures as in the baseline sessions. Each participant played the same piece of music in front of the mock jury panel at both sessions. The MRI session included the same imaging sequences as in the first scanning session, with the only differences being that 1) each participant's post-intervention performance video was used for the second completion of the fMRI anxiety-provoking task, and 2) the N-back task letter stimuli and order of stimuli was different post-intervention.

Data Analysis

Questionnaire Data

Quantitative data analysis was conducted using IBM SPSS Statistics (Version 31.0.1.0 (49)). Paired samples t-tests were used to investigate differences between pre- and post-intervention STAI-T (Trait Anxiety) scores, KMPAI (total score as well as domain 1 and domain 2 scores), MfM scores, MAAS scores, and CMDQ scores. For STAI-S (State Anxiety) scores, Repeated Measures ANOVA was used to examine interactions between condition (i.e., pre- vs post-performance) and time point (pre- vs post-intervention). Bonferroni correction was applied to t-tests and ANOVAs.

fMRI Data Pre-processing

Statistical Parametric Mapping (SPM12) was used to complete the following pre-processing steps for the two fMRI tasks: realign the images to control for motion, normalize the images using the Montreal Neurological Institute (MNI) brain template, then smooth the data using a 6mm Gaussian kernel. First-level analyses were performed following pre-processing (described in the subsequent sections).

Task fMRI Data Analysis

In the anxiety-provoking task, the contrast of interest for each participant was the brain activity left when the control video blocks were subtracted from the anxiety-provoking video blocks. For the N-back task, the contrast of interest was the Press for 2-back minus Press for X blocks. All contrasts were then entered into respective second-level random effects analyses to compare participants' neural activation from pre- to post-intervention, using paired samples *t*-tests. The significance threshold was set to an uncorrected $p < 0.005$ at the whole brain level, and False Discovery Rate-corrected (FDR-corrected) $p < 0.05$ at the cluster level. Age was included as a covariate in paired t-tests for both the anxiety-provoking and N-back tasks. For N-back task performance (reaction time and number of errors) and visual analog scale ratings, we used Repeated Measures ANOVA to examine interactions between condition (i.e., 2-back vs X, own video vs control video) and time point (pre- vs post-intervention). Bonferroni correction was applied to t-tests and ANOVAs.

Thematic Analyses of Group Exploration Body Mapping Session Transcripts

Thematic analyses were conducted on transcripts from the BMM group exploration sessions, using a process similar to that of Braun and Clarke (2006) and drawing from Saldaña's (2015) coding instructions. Initial notes and observations were first made for all 10 sessions. Open codes were then generated, following an inductive approach, where themes were generated organically from participants' dialogue and reflections (rather than being preconceived, i.e., deductive). First-level coding involved highlighting meaningful sentences and phrases (i.e., participant dialogue that reflected their thoughts and experiences with BMM) from session transcripts within NVivo (Lumivero, 2025) to help organize codes. Second-level coding was performed by highlighting portions of transcribed text that reflected trends across multiple participants that could fit into a 'parent code' or broader theme. Themes were formed based on patterns within second-level codes. A thematic map was generated as a visual representation of dominant themes and subthemes. We aimed to take a reflexive approach by ensuring that the themes captured a core idea or meaning, which can draw together data representing even unrelated topics, as long as the core idea or meaning is present (Braun & Clarke, 2023). As is suggested by these authors, we took this approach with the goal to omit bias (e.g., from excessive positivism). For example, we did not speculate about or develop themes prior to the inductive thematic analysis.

Results

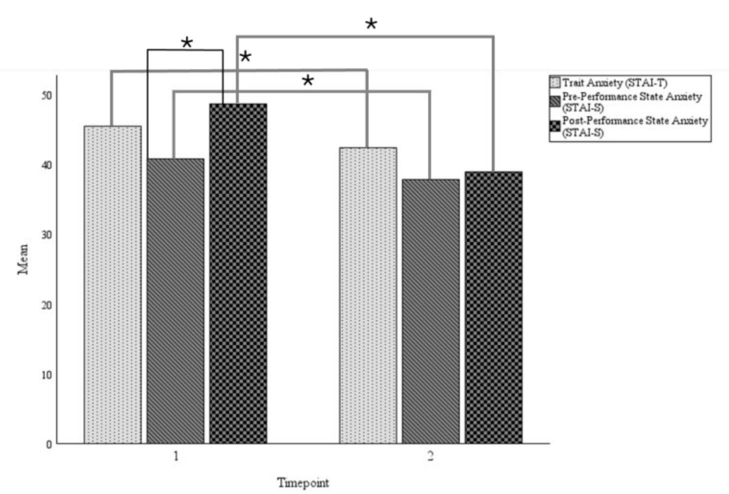
Questionnaire Data

Questionnaire data were first screened for normality by assessing each variable's skewness. We also assessed for outliers. One significant outlier was found for the pre-intervention KMPAI (Domain 2) and the pre-intervention CMDQ composite scores. Sensitivity analyses were run (i.e., the planned analyses without the cases representing significant outliers) to assess the impact of the outliers on results. The sensitivity analyses showed that, for the paired t-tests on KMPAI (Domain 2) and CMDQ scores, the significance level and direction of the effect remained consistent even when excluding the outliers. For the Repeated-Measures ANOVAs (for STAI-S), we tested the assumption of sphericity using Mauchly's test, which was met. Bonferroni correction was applied to significant results.

State and Trait Anxiety

The 2 (performance condition) x 2 (time) ANOVA results revealed a significant main effect of performance condition, i.e., before vs after performance STAI-S score (F (1, 22) = 7.887, p = 0.010, ηp2 = 0.264). Estimated marginal means showed that STAI-S scores were higher post-performance (M = 43.8, SD = 7.77) compared to pre-performance (M = 39.28, SD = 8.85) STAI-S scores (p = 0.010). There was also a main effect of time, i.e., pre- vs post-intervention (F (1, 22) = 18.910, p < 0.001, ηp2 = 0.462). Estimated marginal means showed that STAI-S scores were higher at time 1 (pre-intervention; M = 44.71, SD = 8.30) compared to time 2 (post-intervention; M = 38.37, SD = 8.03), p < 0.001. There was an interaction between time and condition (F (1, 22) = 8.088, p = 0.009, ηp2 = 0.269), whereby post-performance state anxiety was lower at time 2 (M = 38.96, SD = 9.41) compared to time 1 (M = 48.65, SD = 8.65), p < 0.001. Additionally, at time 1, post-performance state anxiety (M = 48.65, SD = 8.65) was significantly higher than pre-performance state anxiety (M = 40.78, SD = 10.04), p < 0.001, yet this difference was not significant at time 2. Finally, paired samples t-tests showed that trait anxiety decreased from time 1 (M = 45.39, SD = 10.17) to time 2 (M = 42.39, SD = 9.08), t = 4.019, d = 0.838, p < 0.001. See *Figure 4*.

Figure 4. Pre- to post-intervention changes in STAI-T and STAI-S scores.

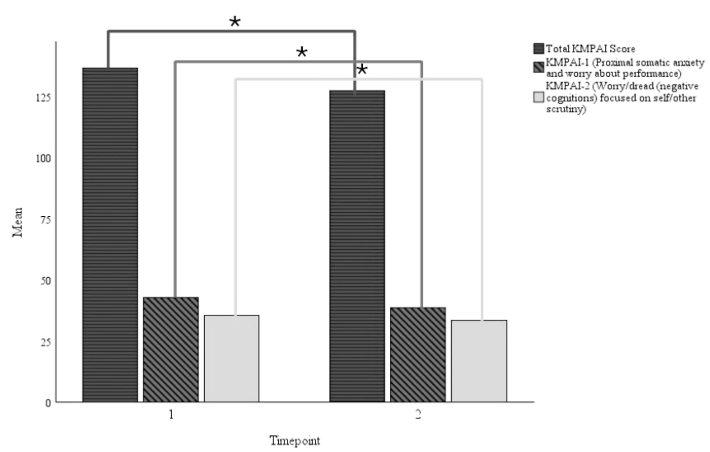


Note: This bar graph represents Spielberger State-Trait Anxiety Inventory (STAI) scores. On the x-axis are two timepoints: 1 (Pre-intervention) and 2 (Post-intervention). Each timepoint has three columns; light grey with dots = trait anxiety (STAI-T), medium grey with diagonal lines = Pre-performance state anxiety (STAI-S), dark grey and checkered = Post-performance state anxiety (STAI-S). The y-axis represents participants' mean scores, ranging from zero to 50 (the highest mean score shown). The highest possible STAI-S or STAI-T score is 80. Lines with asterisks represent significant differences between several columns, discussed above.

Music Performance Anxiety

Paired samples t-tests showed that there were decreases in total performance anxiety from time 1 (M = 136.74 (57%), SD = 28.74) to time 2 (M = 127.65 (53.2%), SD = 31.32), $t = 3.442$, $d = 0.718$, $p = 0.002$. There were also decreases in proximal somatic anxiety and worry about performance from time 1 (M = 43.09 (65.3%), SD = 8.45) to time 2 (M = 38.70 (59%, SD = 12.13), $t = 3.714$, $d = 0.774$, $p = 0.001$. Finally, there were decreases in worry/dread (negative cognitions) focused on self/other scrutiny from time 1 (M = 35.87 (74.7%), SD = 7.42) to time 2 (M = 33.65 (70%), SD = 6.56), $t = 3.443$, $d = 0.718$, $p = 0.002$. See *Figure 5.*

Figure 5. Pre- to post-intervention changes in KMPAI scores



Note: This bar graph represents Kenny Music Performance Anxiety Inventory (Revised; KMPAI) scores. On the x-axis are two timepoints: 1 (Pre-intervention) and 2 (Post-intervention). Each timepoint has three columns; dark grey with horizontal stripes = K-MPAI Total (scored out of 240); medium grey with diagonal stripes = K-MPAI Domain 1 (Proximal somatic anxiety and worry about performance; scored out of 66); light grey with no pattern = K-MPAI Domain 2 (Worry/dread (Negative cognitions) focused on self/other scrutiny; scored out of 48). The y-axis represents participants' mean scores, ranging from zero to 125. Lines with asterisks represent significant differences in several columns and this is discussed in the text above.

Mindfulness and Musculoskeletal Discomfort

No significant changes were found in general trait mindfulness nor musician-specific trait mindfulness. No significant changes were found in musculoskeletal discomfort. Although qualitative reports (see thematic analysis) suggested reduced musculoskeletal discomfort, considerable variability was observed in the CDMQ results and thus no significant quantifiable changes were found.

Task fMRI Data

Anxiety-Provoking fMRI Task

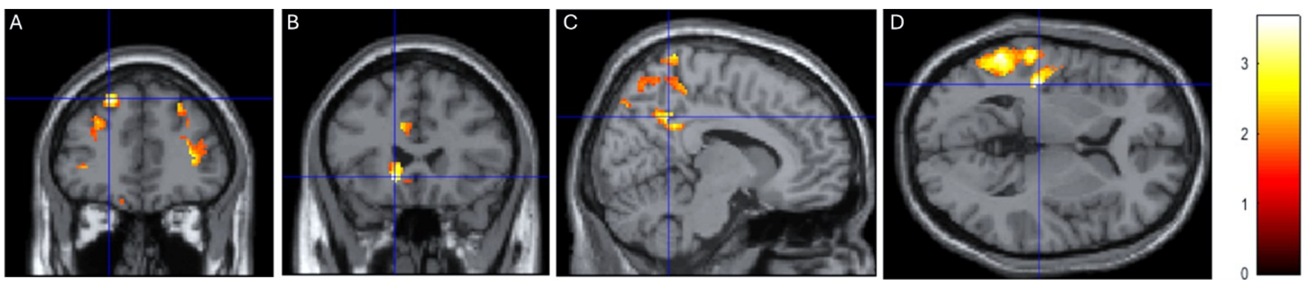
During the Anxiety-Provoking task, paired samples *t*-tests showed several changes in brain activity within participants from pre-to post-intervention. Participants showed significantly decreased activity from baseline to post-intervention when watching themselves compared to another musician in the following brain regions: the left superior frontal gyrus, right precuneus, right posterior cingulate cortex, right opercular inferior frontal gyrus, right middle frontal gyrus, left inferior frontal gyrus, left middle frontal gyrus, left anterior cingulate cortex, left caudate, left superior temporal gyrus, left insula, and left middle temporal gyrus (*Table 2, Figure 6*).

Table 2. Anxiety Provoking Task Results: Pre->Post-Intervention (Participant vs Control Video).

Cluster	Brain Region	MNI Coordinates	*Z*-score	*T*-score
First Cluster: Cluster Size – 5362 *p*FWEcorr: <0.001	Left superior frontal gyrus	-20, 40, 48	3.36	3.90
	Right precuneus	10, -50, 36	3.31	3.82
	Right posterior cingulate cortex	2, -42, 14	3.28	3.77
	Right opercular inferior frontal gyrus	22, 8, 42	3.11	3.53
	Right middle frontal gyrus	28, 24, 40	3.08	3.50
Second cluster: Cluster Size – 3518 *p*FWEcorr: 0.007	Left inferior frontal gyrus	-18, 34, 12	3.84	4.66
	Left middle frontal gyrus	-20, 34, 16	3.68	4.39
	Left anterior cingulate cortex	-10, 28, 4	3.60	4.26
	Left caudate	-14, 24, -6	3.42	3.99

	Left superior frontal gyrus	-12, 62, 14	3.03	3.42
Third cluster: Cluster Size – 2634 *p*FWEcorr: 0.035	Left superior temporal gyrus	-34, -56, -4	3.93	4.80
	Left insula	-36, -22, 6	3.39	3.94
	Left inferior frontal gyrus	-42, -22, 8	3.35	3.89
	Left middle temporal gyrus	-58, -48, 4	3.12	3.55

Figure 6. Anxiety Provoking Task Where Post<Pre-Intervention.

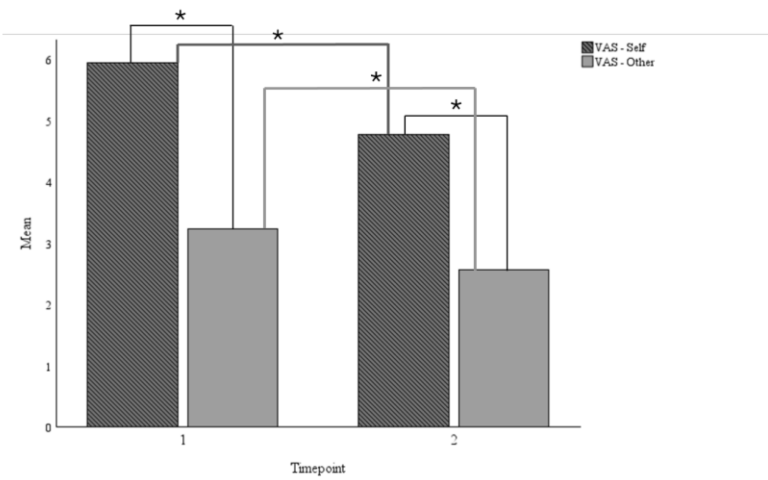


Note: This figure displays four brain cross-section images (from a template provided by SPM12) with fMRI results from the anxiety-provoking task superimposed. Yellow, orange and/ or red areas, highlighted with blue crosshairs, depict brain regions where BMM participants showed significantly less brain activity post-intervention compared to pre-intervention. Each image has the letter A, B, C, or D next to it, depicting the following brain areas: A) Left superior frontal gyrus, Right opercular inferior frontal gyrus, right middle frontal gyrus, left inferior frontal gyrus, left middle frontal gyrus; B) left caudate, left Anterior Cingulate; C) Right precuneus, right posterior cingulate; D) Left superior temporal gyrus, left middle temporal gyrus. To the far right of the image, there is a legend that represents *T*-scores. This legend contains colours ranging from black (corresponding to a *T*-score of 0) to white (corresponding to a *T*-score of 5), with red, orange, and yellow in between 0 and 5). Lighter coloured brain regions correspond to higher *T*-scores and darker coloured regions correspond to lower *T*-scores.

Data from the Visual Analog Scale (VAS; i.e., the scale from 1 (extremely relaxed) to 10 (extremely anxious) shown to participants right after completing the anxiety-provoking task) were screened for normality by assessing each variable's skewness. We also assessed for outliers. No VAS variables were skewed nor were there any outliers. For the Repeated-Measures ANOVA, we tested the assumption of sphericity using Mauchly's test, which was met. Bonferroni correction was applied to significant results.

Results of the VAS revealed main effects of condition and time in a 2 (time) x 2 (condition) ANOVA. For the main effect of condition ($F\ (1, 22) = 86.989$, $p < 0.001$, $\eta p2 = 0.798$), estimated marginal means showed that self-reported anxiety was higher for the 'Self' (i.e., own performance video; M = 5.37, SD = 1.59) vs 'Other' (i.e., other musician's performance video; M = 2.90, SD = 1.47) condition ($p < 0.001$). For the main effect of time (F (1, 22) = 8.716, $p = 0.007$, ηp2 = 0.284), estimated marginal means showed that self-reported anxiety during both the 'Self' and 'Other' conditions were higher at time 1 (Self: M = 5.96, SD = 1.97; Other: M = 3.24, SD = 2.01) compared to time 2 (Self: M = 4.78, SD = 1.81; Other: M = 2.57, SD = 1.34). No time by condition interactions were found. See *Figure 7*.

Figure 7. Pre- to post-intervention changes in VAS scores



Note: This bar graph represents Visual Analog Scale (VAS) scores. On the x-axis are two timepoints: 1 (Pre-intervention) and 2 (Post-intervention). Each timepoint has two columns; dark grey with diagonal stripes = VAS of anxiety during one's own performance (VAS – Self) and light grey with no pattern = VAS of anxiety during the other musician's performance (VAS – Other). The y-axis represents participants' mean VAS scores, ranging from zero to 6 (i.e., the highest mean score shown on this 1-10 scale). Lines with asterisks represent significant differences in several columns and this is discussed in the text above.

N-back Task

N-back performance data were screened for normality by assessing each variable's skewness. The only variables that had a skewness +/-3 were pre- and post-intervention accuracy on the 'Press for X' condition of the N-back. Neither square root nor logarithmic (Lg10) transformation could reduce the negative skewness. This skewness arose from a ceiling effect where scores below 100% (64/64) represented an outlier on this control condition of the N-back task. This is a standard effect for the control condition of the task when administered to healthy adults, suggesting that the control condition is producing the expected outcome. This ceiling effect was also the reason why the skewness of both pre- and post-intervention Press for X were resistant to both square root and logarithmic transformations. We also assessed for outliers, and six were found across both pre- and post-intervention accuracy on 'Press for X', with three outliers per condition. Sensitivity analyses were not conducted for the N-back accuracy Repeated-Measures analysis due to high number of outliers on the Press for X condition (with the outliers representing scores less than 100%). All outliers on the Press for X condition had scores ranging between 60 and 63. For the Repeated-Measures ANOVA, we tested the assumption of sphericity using Mauchly's test, which was met. Bonferroni correction was applied to significant results.

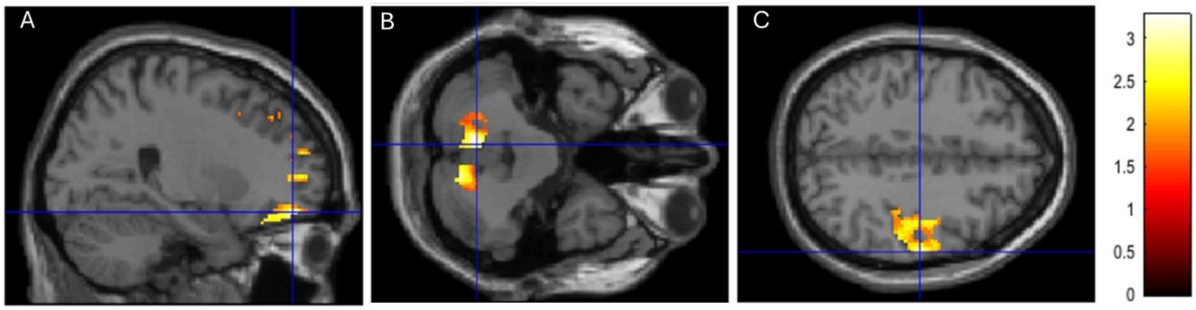
Paired samples *t*-tests revealed that, during the N-back task, participants showed significantly more brain activity after the intervention compared to baseline in the right middle frontal gyrus, right orbitofrontal cortex, midbrain, left lingual gyrus, right medial prefrontal cortex, right dorsolateral prefrontal cortex, bilateral cerebellum, right postcentral gyrus, and right precentral gyrus (*Table 3, Figure 8*).

Table 3. N-back Task Results: Post->Pre-Intervention (2-back vs X)

Contrast	Brain Region	MNI Coordinates	*Z*-score	*T*-score
First cluster: Cluster Size – 5362 *p*FWEcorr: <0.001	Right middle frontal gyrus	26, 42, 6	3.77	4.54
	Right orbitofrontal cortex	18, 10, -14	3.39	3.94
	Midbrain	-2, 0, -20	3.15	3.60
	Left Lingual gyrus	-12, -46, 0	3.13	3.57
	Right medial prefrontal cortex	8, 26, -16	3.10	3.52
	Right dorsolateral prefrontal cortex	12, 56, 16	3.05	3.44
Second cluster: Cluster Size – 3036 *p*FWEcorr: 0.038	Left cerebellum (8)	-6, -62, -40	3.29	3.78
	Right cerebellum (8)	14, -72, -40	3.02	3.41
Third cluster: Cluster Size – 3012 *p*FWEcorr: 0.040	Right postcentral gyrus	60, -16, 42	2.92	3.27

Right precentral gyrus	50, -8, 56	2.88	3.21

Figure 8. N-back Results where Post- > Pre-Intervention.

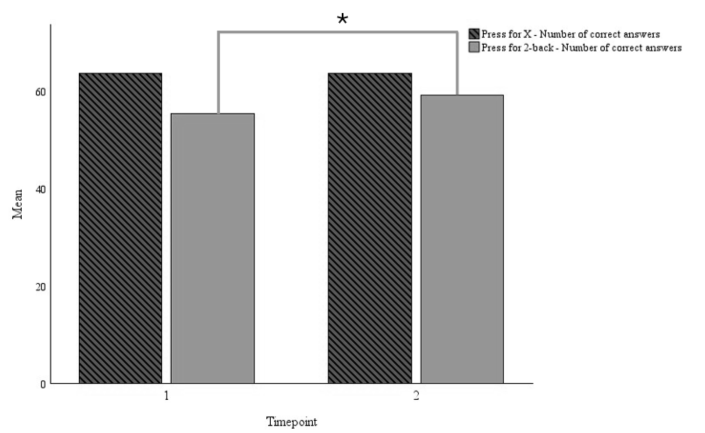


Note: This figure displays three brain cross-section images (from a template provided by SPM12) with fMRI results from the N-back task superimposed. Yellow, orange and/ or red areas, highlighted with blue crosshairs, depict brain regions where BMM participants showed significantly more brain activity post-intervention compared to pre-intervention. Each image has the letter A, B, or C next to it, depicting the following brain areas: A) Right orbitofrontal gyrus, middle frontal gyrus; B) Bilateral cerebellum; C) Right precentral gyrus, right postcentral gyrus. To the far right of the image, there is a legend that represents *T*-scores. This legend contains colours ranging from black (corresponding to a *T*-score of 0) to white (corresponding to a *T*-score of 5), with red, orange, and yellow in between 0 and 5). Lighter coloured brain regions correspond to higher *T*-scores and darker coloured regions correspond to lower *T*-scores.

Furthermore, a 2 (time) x 2 (condition) ANOVA revealed changes in N-back task performance. There was a main effect of condition for both reaction time or RT (F (1, 22) = 81.631, $p < 0.001$, ηp2 = 0.788) as well as accuracy, or number of correct responses (F (1, 22) = 64.434, $p < 0.001$, ηp2 = 0.745. Estimated marginal means showed that RTs were faster for Press for X (M = 0.51, SD = 0.05) than Press for 2-Back (M = 0.59, SD = 0.07), $p < 0.001$. They also revealed that accuracy was higher for Press for X (M = 63.76, SD = 0.52) than Press for 2-Back (M = 57.39, SD = 3.92), $p < 0.001$.

There was also a significant interaction between time and condition (F (1, 22) = 18.452, $p < 0.001$, ηp2 = 0.456). Specifically, participants showed higher accuracy for Press for 2-Back at time 2 (M = 59.35, SD = 4.10) than time 1 (M = 55.43, SD = 4.68), $p < 0.001$. No time by condition interactions were found for RT. Only correct responses were included in the calculation of reaction times. See *Figure 9*.

Figure 9. Pre-to-post-Intervention Changes in N-back Accuracy



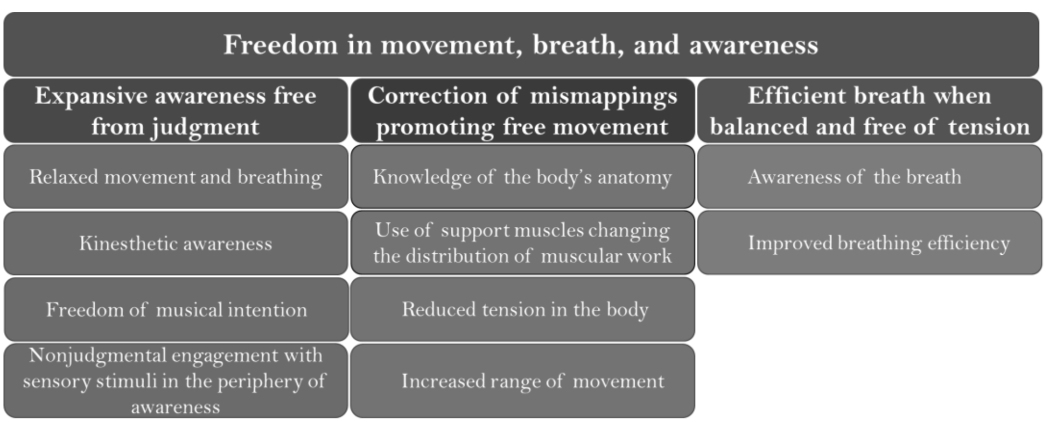
Note: This bar graph represents number of correct answers on the Press for X and Press for 2-Back conditions of the N-back task. On the x-axis are two timepoints: 1 (Pre-intervention) and 2 (Post-intervention). Each timepoint has two columns; dark grey with diagonal lines = Press for X and light grey with no pattern = Press for 2-Back. The y-axis represents participants' mean number of correct answers, ranging from zero to 64. Lines with asterisks represent significant differences in several columns and this is discussed in the text above.

Thematic Report from Group Exploration Body Mapping Sessions

Freedom in movement, breath, and awareness

Throughout all BMM group exploration sessions, the above-mentioned dominant theme emerged based on participants' statements about expansive, nonjudgmental awareness, free movement, and efficient breath. See *Figure 10* for a thematic map. Click here for supplementary material on the thematic analysis process.

Figure 10. Thematic Map



Note: This figure represents a thematic map based on group exploration BMM discussion transcripts. All themes are represented as boxes in this figure. The top box represents a dominant theme, and the three boxes below it represent subthemes. The remaining boxes below each key subtheme represent further subthemes.

Expansive awareness free from judgment

This subtheme within ‘Freedom in movement, breath, and awareness’ encompasses several other subthemes, representing statements about participants’ experiences with inclusive awareness.

Relaxed movement and breathing: This subtheme within ‘Expansive awareness free from judgment’ represents statements about increased relaxation and reduced tension in movement and breath when expanding one’s awareness in a nonjudgmental manner. When the Body Mapping Educator asked participants to play their instruments while progressively expanding their awareness from a narrow, concentrated awareness to a larger, more vast awareness, a participant said they noticed a “Freer bow” while playing. Freedom and relaxation were not only experienced in movement but also in breathing. For example, a participant said: “I could hold it longer!” in reference to their ability to hold a note longer after freeing their eyes to include various stimuli in their awareness while playing; this indicated less restriction in the breath. Another participant said the following about what they noticed while practicing inclusive awareness during playing: “I was trying to relax it, like you say, I was looking at that sign there and, you know, just took my mind off the note, and it relaxed it.”

Kinesthetic awareness: This subtheme within ‘Expansive awareness free from judgment’ represents statements about improved ability to sense the body’s positioning in space when expanding one’s awareness. When completing an exercise involving backwards walking to find a balanced posture, a participant said: “It informs a lot about just that whole backside of the body. We have to have like “spidey sense” back there if we’re going to move backward in a room. So, it brings everything into acute awareness, and it changes how we stand.” This statement indicated an increase in the participant’s kinesthetic awareness of what is behind them in space. Another participant experienced a shift in their kinesthetic awareness at the back of their head specifically. They said “This will help. I have to refigure all this. This is very good” when the Body Mapping Educator walked them through an exercise to gain awareness of the Atlas-Occipital joint; this occipital region of the head houses the occipital lobe of the brain, which contains the brain’s primary visual cortex. Specifically, the participant was instructed to feel as though the image of the music on the page is floating in from the back of their head. The participant mentions that this will help in reference to the awareness at the back of the head helping prevent the neck from pulling down and forward, making it less stiff while playing. In another group exploration session, when the Body Mapping Educator discussed awareness of the back and front of oneself while playing, another participant began to ponder awareness of the back of themself as well and said: “I'm very front facing. I'm realizing that I don't have that backwards sense.”

Freedom of musical intention: This subtheme within ‘Expansive awareness free from judgment’ represents statements about increased confidence in the notes being played when freeing one’s intention; specifically, this was done by tuning into movements and expanding awareness in a nonjudgmental manner while playing. A BMM technique, involving breathing in sync with musical phrase, was applied to promote such freedom. When breathing in sync with the music they were playing, a participant stated that: “[…] I go at the top of a phrase, everything…contracts…” This indicated an intuitive awareness of musical phrasing. This same participant said the following in reference to their experience playing while cueing such awareness (e.g., setting the hand on the keys to direct attention to the body in movement while playing):

> You know, that in mind - and the passages where it's usually like arpeggiations and things like that, where I never feel totally confident. Even if I feel confident, it might not come out, and just setting my hand – It's just in the warmup, like the beginning of the warmup, which really surprised me. […] I guess the thing is, it is the accuracy that astounded me. […] I'm waiting for the one that wasn't going to turn out or the sequence that wasn't going to happen, but they just kept happening because I just kept putting my hand there.

As is exhibited in the above quote, the participant's attention is not on judgmental thoughts, but rather on the body's intuitive sense of the next movement to make to produce music. The participant describes this experience as astounding because of the expectation that a note would not turn out, but that they often do turn out because of this cueing from the body. The Body Mapping Educator describes this experience as freedom of musical intention, where the playing is thought of as more objective than subjective, simply watching the hands do what they have learned to do (e.g., trusting one's expertise in playing a piece). Another participant expressed this idea by saying: "It's like, I don't even need to know the music" in reference to this technique allowing musicians to set musical intention within the body.

When using the body to set musical intention, another participant said: "Yeah, I feel the sensations from the whole body", exemplifying freedom of musical intention. This was in response to the Body Mapping Educator's statement: "When you marry your musical intention with something that's so visceral, it's your entire torso, it can't help but come out, you know, the arms will express that, and that will be at the focus of your attention. When you're performing, you are wholly playing it. It's not your fingers playing it."

Nonjudgmental engagement with sensory stimuli in the periphery of awareness: This subtheme within 'Expansive awareness free from judgment' represents statements about engagement with sensory stimuli when expanding one's awareness in a nonjudgmental manner. For example, one participant noticed external sensations such as shapes and colours around the room while playing; she said: "I was looking up and I was trying to take note of the black round screen […] skeleton, and then the white." Another participant exhibited fluid awareness, taking in broad attributes of stimuli without rigid naming of objects or sensations: "I feel like my awareness was kind of just shifting. I was just kind of like, oh, that's like, orange here. And then I was like, oh, there's a light, and there's things where I almost didn't really label like, oh, that's a chair." Another participant said: "I was aware of the stipples on the ceiling, the squares of the nod drains, whatever those are" in reference to what they noticed after playing while practicing inclusive awareness, starting their playing in a normal way with the eyes closed, then slowly opening their eyes and widening their peripheral awareness.

This expansive awareness was also described by a participant as a softening, specifically when doing an inclusive awareness exercise (handwriting while taking in stimuli within the periphery of awareness): “For me, it was softening. It was softening in my hand, especially around the actual instrument because of the pen, and also a softening my mouth.” While playing, this same participant noted that: “This side is a lot more open, which inevitably helps this side” in reference to one side of their body opening up to their attention while practicing inclusive awareness.

This expansive, nonjudgmental awareness also took the form of becoming comfortable with the performance space. One participant applied this concept and stated: “So as the two were performing just now, I was thinking: Okay. Who’s here?”, indicating less judgement and more curiosity and openness towards the space and the people within it. Another participant described how they applied inclusive awareness in a performance setting, becoming comfortable with the people around, being objective and nonjudgmental: “Yeah, I tried it a little bit this afternoon even in this performance situation here, you know, somebody was talking through the piece […] today I'm just like, I'm just going to take these people in and they're all here for a nice concert.”

Such nonjudgmental engagement also included feelings of pleasure and positive sensory experience while playing. For example, a participant said: “I feel the shirt on my arms, so when I dropped my arm around, it feels soft when resting” while bringing sensations into their awareness – particularly, something that feels nice and pleasurable. Relatedly, another participant said the following when practicing open, free awareness of sensations (e.g., how the instrument feels) rather than overly analytical awareness while playing: “And you know when I practice, I think I sometimes more and more, you know, I feel the instrument and it feels good. But that's new for me. […] but in audition or whatever, it’s confusing.” The participant referred to feeling confused about these positive sensory experiences with the instrument, and the Body Mapping Educator explained that such feelings can arise from focusing on the audience analytically rather than aiming to simply experience the music with them.

Two participants struggled with the idea of noticing stimuli in the periphery of awareness in a nonjudgmental way. Specifically, they scanned from one stimulus to another while playing, as opposed to making the musical piece the central focus while inviting stimuli into the periphery of awareness. By focusing more sharply on stimuli while scanning, these two participants highlighted the important dichotomy of scanning (analytical) versus inclusive awareness (nonjudgmental). One participant said the following in reference to their finding difficulty reorienting attention to the piece after focusing it elsewhere (i.e., when scanning from one stimulus to another):

> But I'm afraid of these feelings, because if I start, oh, that's the cars, I'm afraid to come back to, you know, focus and concentration […] I might just make mistakes, start making mistakes because I don't have control on that, and, that's what I said to you earlier: that it's probably not lack of attention. It’s just a distraction. […] I just sometimes cannot even find a spot in the book where I was. That’s how distractive it is.”

This same participant said the following as well: “First of all, I cannot see, well, it's not too sharp. It's too close for me. So, I think it’s uncomfortable, so I move my eyes away again, and if I stay away from the strings and the bow, I need that contact” and “I focus on what I do, but then my eye's constantly moving. And it's not that I'm staring at the skirt, but I see it very well, and then I start looking at you and then I hear this, but there is not enough attention concentration for this one, because I'm not paying attention to what I'm doing while I'm scanning." These quotes indicated that the participant was moving their eyes while playing (e.g., from another participant's skirt to the Body Mapping Educator, etc.) as opposed to keeping their eyes focused on the instrument or music while letting shapes and colours into peripheral awareness. Notably, the participant was allowing their awareness to drift from one thing to another and staying focused on a given object or sensation for too long; the Body Mapping Educator provided clarification to the participant about being more aware of their periphery in the background while playing, without being overly focused on a given item/object in the room.

The analytical component of scanning as opposed to inclusive awareness was further exemplified by the participant's statement that "[…] I am focusing too much on what I just observed, I start looking for the details." Similarly, the other participant in the session said: "It's like when I'm aware of something, I want to analyze what I'm aware of." These participant quotes underline the important difference between scanning and inclusive awareness. In the process of a participant transitioning between discomfort when scanning and grasping the concept of inclusive awareness, they said "I struggled with it at first, but then when I just let it go, it played."

Correction of mismappings promoting free movement

This subtheme within 'Freedom in movement, breath, and awareness' encompasses several other subthemes, representing statements about participants' experiences correcting their mismappings and moving based on the body's anatomy – processes that led to free movement.

Reduced tension: This subtheme within 'Correction of mismappings promoting free movement' represents statements about reduced tension in the body when moving based on the body's anatomy. Participants mentioned feelings of reduced tension when the Body Mapping Educator asked them to be aware of a given body sensation, or to adapt their movements according to participant-specific needs, instrument, and anatomy. When bringing their awareness to jaw tension, for example, a participant said: "I'm so glad you said that about gritting your teeth because I just let go of mine and then my neck released." When practicing adaptive movements to reduce tension, another participant said: "I'm more free with it" after practicing humeroscapular rhythm through an arm swinging exercise guided by the Body Mapping Educator. Another participant experienced a smoother movement when lifting their forearms from the ulna bone (pinky) side versus the radius bone (thumb) side. They said: "Yeah, if I put it further, it's easier for me to feel that wave there." The wave refers to the gradual releasing of arm muscles as the ulna bone supports the lift. Another participant remarked that: "Oh, that's a huge change […] I feel it a lot right on top" while playing using the ulna bone (pinky) side of the forearm for support. This was said after the Body Mapping Educator noticed the mismapping where the participant was bending their arm from to play; the Educator noted that if the participant is stiff here, it is because they are trying to bend from the top of the arm instead of where the joint is.

Reduced finger tension was found as well. One participant said: “This is sort of where I start feeling like I lose that connection to my thumb […]” while playing. This quote was in reference to the Body Mapping Educator suggesting that there is something stuck around their thumb joint while playing the passage, where they lose a bit of flexibility in the thumb. The Body Mapping Educator suggested that this loss of connection to the thumb could arise from the participant using the radius (thumb) of the forearm versus the ulna (pinky) to support the instrument. Another participant was aware of finger tension as well, stating that: “I feel like I'm muscling it from in between the fingers.” This quote was in reference to the dull feeling the participant had when trying to spread their fingers on their instrument. The Body Mapping Educator then noticed that the participant was using only half of the length of their fingers due to a mismapping as to where the finger joints begin. When trying the spreading using the full length of the fingers, the participant said the following (in reference to reduced tension): “Wait, this actually feels… like that changes.”

Increased range of movement: This subtheme within ‘Correction of mismappings promoting free movement’ represents statements about a greater range in the body’s movement when moving based on the body’s anatomy. These statements encompass feelings of lengthened body parts as well as a wider range of body positions that can be achieved. For example, one participant said: “It (*the arm*) feels more elongated” in reference to their feeling the *whole* arm while playing (rather than just a portion of it), following guided humeroscapular rhythm practice with the Body Mapping Educator. Once the participant stopped tensing the muscles that held their shoulder blade down – which created a general feeling of tension – the arm itself felt longer. This same participant said: “It feels more open” in reference to the humeroscapular rhythm in their arm movement allowing shoulder muscles to soften and release. The force of one’s arm movement is also implicated in range of movement. For example, another participant said: “Much more weight” in reference to being able to deliver the whole weight of the arm into their instrument, using humeroscapular rhythm (leading from the back of the elbow).

Use of support muscles changing the distribution of muscular work: This subtheme within ‘Correction of mismappings promoting free movement’ represents statements about adjusting to the new feelings associated with using support muscles, with the goal to move based on the body’s anatomy. Participants expressed various adjustments in posture and body positioning after engaging these support muscles, as well as newfound grounding and support.

One participant noticed increased ease in movement when lifting the forearm in a way that draws from support muscles. They said: “I can feel the difference, and I can still feel my shoulder moving. It’s not like… it’s angry because I’m pushing it to do the whole movement.” The participant noticed this change specifically when lifting their arms from the ulna (or pinky) side of the forearm, whereas when lifting from the radius (or thumb) side, the movement felt more forced and difficult for the participant. Relatedly, this same participant said: “It feels very grounded” when lying on their back, practicing moving the arm from the ulna side (guided by the Body Mapping Educator), noticing smoother movements and less muscular work. When comparing the feeling of lifting the arms from the radius (thumb) side (referred to as the curtain rod) versus the ulna (pinky) side (referred to as the butler’s tray), another participant said: “Yeah, I find that whenever I do the curtain rod, it's like I can feel this big pull of everything overcompensating to pull my arms. […] I don't feel it at all, actually, when I think about the butler." Another participant said: "I feel it's in my core there when I do that" when using the butler's tray lifting analogy for engaging deep support muscles. On a similar note, another participant said: "I feel more balanced, more straightened out. I am looking lower than I thought I would, but it feels more natural, I guess. […] It feels like I can relax" when lifting their instrument via the ulna side of the arms rather than using musculature in the chest to help lift it.

The backwards walking posture exercise led to changes in balance as well. A participant said: "I feel like I can walk a lot more naturally" while doing backwards walking, carrying their large instrument. Two participants said the following, respectively: "Feels like I'm more forward than I expected to be" and "I feel very far forward" in reference to their body positioning after taking three backwards steps. Another participant noted that: "[…] you feel like you're almost missing things when your knees are slightly bent, and your hip is back and your chest is forward, but you're not." Another said: "I feel way more in my shoulders", in reference to where the participant felt the musculature working after raising their instrument normally after backwards walking, then reverting to normal standing. In reference to this participant's feelings of weight distribution following backwards walking, they remarked that: "Staying in this position, I feel way more in front of my foot I feel a little bit more in my lower back." They also said: "I don't really feel much weight at all on the outside, it feels mostly on the inside of the feet" in response to the Body Mapping Educator asking them to note where they feel the weight distribution following backwards walking. Another participant played their instrument after backwards walking and said: "I feel about twice as wide on my left side than on my right side." This was in response to the Body Mapping Educator's question about whether it feels different to play after doing an exercise to keep the elbows up (and using the ulna bone for support) following backwards walking.

After practicing a sitting exercise designed to engage the sit bones for support, a participant said: "I'm leaning forward and when I lift one leg, a lot of weight goes into it" when practicing using deep lumbar support muscles when sitting at the bench they use while playing. This same participant also said: "[…] feels like it throws everything off, you know? All of a sudden, I'm struggling to, struggling to bend on this" when, at first, they had difficulty adjusting to staying on the two sit bones and having independent leg movement. The Body Mapping Educator replied to the latter part of the quote: "Because it's throwing you over onto that sit bone," indicating the new weight distribution. Another participant said: "I'm beginning to feel it and they're definitely shaky" in reference to feeling the ulna working when raising their arm, lying on their side (on a mat on the floor). The Body Mapping Educator noted that this shakiness helped uncover muscle weakness in the ulna side bone to be worked on. These quotes highlight the various adjustments to muscular effort when engaging support muscles.

Knowledge of the body's anatomy: This subtheme within 'Correction of mismappings promoting free movement' represents statements about participants learning how the body works and the adaptive functions of different body parts. Participants noted several personal discoveries. One participant said: "So you're getting awareness of your feet, but no one ever explained why that works and I think it's important to know why" in reference to a discussion about how other known musicians use their bodies to carry out movements. Another participant said the following in response to the Body Mapping Educator's question about what stood out to the participant about the class: "When I went home, I just began thinking about the bone placements, especially my forearm, and how moving would not only affect the physical form, but also perhaps the action of the playing motion." In response to this same question, another participant said: "Just learning the hands, the shoulders, the pelvis, the legs, postural on the podium knowing to find the tripod at my feet." Another participant said: "Yeah, I think that was the biggest takeaway to say, oh? Is that what I'm up to? Is that not okay?" in reference to having learned about unconscious movement habits while playing and in daily life, which could impede playing (for example restricting breathing while playing).

Course content on the body's anatomy was also discussed in reference to a participant's difficulty with certain arm raises when playing the A or B string on their instrument; they said: "Yesterday (*day of the course*), this whole connection to the collar bone and the scapula, that was very important. […] A mismapping for me was that this is the train (scapula), and this is the caboose (humerus)." The quote is in reference to the participant's learning of humeroscapular rhythm, with the 'train' being the humerus and 'caboose' being the shoulder blade. In the participant's mind, this had been reversed. In reference to previous course material from the day prior, this same participant noted an increased awareness of the spine: "When you talked about the elongation of the springiness of the spine, I think that's amazing. I didn't think about that. I found my lower spine doing a little bit of a curve when I tried to do that."

Participants were also able to map course content about the body's anatomy to their previous knowledge (e.g., from their music lessons). For example, a participant said: "It's so weird to try to think about movement there, because like I said yesterday, I was told "elbow still," and so it was very, very locked up." This was in reference to how the participant felt playing open strings on their instrument while practicing humeroscapular rhythm. Relatedly, this same participant said the following in reference to the Body Mapping Educator's teachings about tension and its impacts on the body: "What you were saying yesterday about tension causing you to physically play differently…I didn't really understand that connection until you said it, and so that makes a lot of sense – it would always just confuse me and make me worry more." Such confusion about tension was shown by another participant who noted that: "I used to also have pain here because I didn't know how to move my arm properly, especially on the A string. I know I used to get really frustrated and I couldn't find an answer because I was holding on the A string. I didn't know how to support my arm weight properly." This quote came about when discussing thumb pain and tension while playing with the Body Mapping Educator, and how the size of the participant's hands could impact such tension.

The arm joints were discussed as well, and a revelation about the anatomy of the arms was shown by a participant who said: "This is the end of my arm, that's really interesting to me because I think of this as my wrist, but no you're right, it's my arm" in response to the Body Mapping Educator's question about whether they are clear on the wrist bones, and where it feels their wrist bones are on their right hand.

After reflecting on the content of the full day course, a participant noted an awareness of thumb tension as well: "I had tension for many years. I was pinching" in reference to something they realized they would like to focus on after taking the BMM course (pinching of the thumb on the bow side of the instrument). In the context of movement practice, another participant said the following when discussing with the Body Mapping Educator how they hold their instrument, and how knowledge of the thumb's length is crucial for playing: "That was new. I mean, I knew that, but I never thought of it." This quote was in reference to the Body Mapping Educator examining the way the participant holds their instrument, saying: "We want to see if your brain can take in the reality that the thumb goes all the way down to here." Relatedly, another participant said the following when speaking with the Body Mapping Educator about how the finger joints can be used adaptively to play their instrument: "I know that this is what we should do but I didn't know why. Now I feel like I need to explain that." This quote highlighted the importance of understanding why certain movements are adaptive for the body. This same participant also remarked on the Body Mapping Educator's emphasis on the body in movement and the importance of being able to transition between different positions, without getting stuck in one single position:

> It's all very fluid. I really appreciate that as well, that you're talking about the fact that we can be in and out of these positions […] I think one time, I went to some kind of back thing and they were like, "You can never sit on a couch. Sitting on a couch is the worst thing you could do," but I was like, "Well, this house is not for me." Right? And they're like, "No, you only sit in this one position where your body would be happy." And I was like, "No. My body might be happy, but I won't be happy." So that's what I really appreciate from today, the fluidity and the movement, and how it all relates. That's really beautiful."

Efficient breath when balanced and free of tension

This subtheme within 'Freedom in movement, breath, and awareness', encompasses several additional subthemes, representing statements about efficient breathing when using support muscles to achieve balance, taking the tension out of other overworked muscles.

Awareness of the breath: This subtheme within 'Efficient breath when balanced and free of tension' represents statements about noticing one's breath quality in different circumstances and body positions. To promote awareness of the breath, the Body Mapping Educator would instruct participants to play or sing in their habitual way and notice any patterns in their breathing, which she would then proceed to work with according to the participant's specific issues. Prior to playing in the group exploration session, one participant described some of their habitual feelings while playing and related them to the course content the day prior:

> I usually find it counterproductive putting my shoulders back and keeping them down less. It limited my voice, my breathing, and everything, and kept it so tapered down that I wasn't using like a quarter of my chest – because it was all just held down with the fascia – was really tight. You could feel it when I was trying to take a deep breath. […] It's not coming above here (*part of the chest*) at all, and so, feeling the back body, I've been doing that, you

> know, really breathing to all four corners of the chest. So, coupling that with how much more breath I can get, like, I have a piece coming up with a 15-second-long note that's held and modulated, and I was like: "how am I going to get that?" I'm always tapering off at the end, but now that I think of this, I think I can really get into that and get there.

This same participant stated the following in reference to the way they habitually feel while playing, after playing a few bars; specifically, they noticed themself running out of breath at a certain point in the piece: "[…] so I just ran out of gas. You can feel it; it stops right here. You're just trying to go for it, but you know you're going to run out, so you're just panicking trying to figure out any sort of embodiment you can do to get that little extra at the end." This participant also remarked that, while playing in their habitual way, there is tension underlying some of their breath quality issues: "[…] my anxiety, it pulls my jaw down, and it wants to keep it there. This tightness here…just– it locks it all down."

Another participant noted the following about their habitual feelings while playing, in response to the Body Mapping Educator's question about why they are used to not taking full breaths all the time while playing: "[…] sliding into old habits, like not staying conscious of taking good breaths all the time." They also said: "I feel like it's mostly confined to like here (*upper ribs*), in terms of a not good breath, I feel like I'm not feeling the full extension" and "I feel like my exhale, there's tension in the front still pushing rather than letting go." They also remarked that**:** "The more empty my lungs are, the more pressure I feel on the spine."

Improved breathing efficiency: This subtheme within 'Efficient breath when balanced and free of tension' represents statements about the breathing efficiency participants experienced when practicing techniques for reducing tension and balancing posture. One participant said: "With that modification of moving the collarbone with the ribs and getting that extra quarter of air should really help" in reference to their feeling a greater breathing capacity after adapting movements associated with the breath while playing. This same participant also said: "[…] if I relax, not trying to go too far back and down, but trying to find that middle lift…and then, yeah. It gives me a lot of breath room" when attempting to find a balanced posture that best supports their breath while playing, with guidance from the Body Mapping Educator. After trying the backwards walking exercise along with the abovementioned breathing techniques, the participant said: "I could get more room, I definitely felt it." Another participant stated that: "I feel like my breath in is a lot more efficient" after having achieved a balanced posture while playing (through backwards walking, balancing the head on the atlas-occipital joint, and allowing a slow rib descent with a long, slow exhale). Relatedly, when a participant was making a comparison between their habitual way of playing and their playing when balanced (through BMM exercises), the participant remarked "It's a little bit thinner […] there's a little bit of tension" about the quality of sound when playing in their *habitual* way after having practiced in a more balanced, supported way.

Discussion

The present study provides preliminary neuroimaging findings that a three-week-long BMM intervention can change the brain activity of musicians with MPA, specifically during a task designed to invoke MPA and during a working memory task. Task fMRI results, along with questionnaire and thematic results, indicate that BMM is a promising approach to reducing MPA. It is worth noting that Boland and colleagues (2025a, 2025b) used an identical imaging protocol and found no pre- to post-intervention differences in brain activity, nor questionnaire scores, among musicians in the control group (who did not have any intervention), suggesting that practice effects were not the reason for the observed changes.

Anxiety, Mindfulness and Musculoskeletal Discomfort

Consistent with our hypothesis and with previous literature on how mindfulness affects MPA (e.g., Boland and colleagues, 2025; Stanson and colleagues, 2022), state anxiety decreased from pre- to post-intervention. The decrease in state anxiety following performing was especially notable. Following the intervention, there were also reductions in trait anxiety, total performance anxiety, proximal somatic anxiety and worry about performance, as well as worry/dread (negative cognitions) focused on self/other scrutiny.

These state and trait-level anxiety reductions may have been facilitated by reduced tension (e.g., Passarotto and colleagues, 2023; Sokoli and colleagues, 2022), improved body awareness (e.g., Buchanan & Hays, 2014; Rader, 2023; Ross, 2022; Salonen, 2018), and enhanced inclusive awareness of external and internal sensations while performing (e.g., Buchanan & Hays, 2014) cultivated by BMM education. Such changes may have led to participants feeling more confident and at ease, both after a performance and in their daily lives.

The BMM course, despite integrating elements of mindfulness (e.g., inclusive awareness), did not lead to changes in trait mindfulness. The variability in participants' self-directed practices over the three weeks may partially account for this lack of group level change. For example, some participants practiced BMM techniques more often than others. Some may also have integrated the more mindfulness-centred components (e.g., inclusive awareness) into their lives more than others. Additionally, there were no significant changes in musculoskeletal discomfort from pre- to post-intervention. Like with trait mindfulness, variability may have partially influenced this result. For example, all participants had varying levels of baseline pain and discomfort. They also practiced BMM techniques tailored to their individual needs during self-directed practice. Despite the lack of change in CMDQ scores, informal self-report at the final testing sessions revealed that many musicians had positive effects with their pain levels. Similarly, the qualitative findings suggest improvement for many of the musicians. There exist various scoring techniques for the CMDQ. For this study, composite CMDQ scores represented the Frequency scores x the Discomfort scores x the Interference scores. This scoring scheme thus allowed us to capture general discomfort scores that accounted for frequency and severity. Results may have been different had we focused on individual body parts or used a different scoring scheme. However, our findings are consistent with Rader (2023), who focused on changes within individual body parts, and did not find notable pre- to post-BMM trends in CMDQ scores, nor any differences between the experimental and control groups' post-intervention CMDQ scores. Perhaps a different questionnaire for this variable is warranted for future research.

Brain Activity during the Anxiety-Provoking fMRI Task

From pre- to post-intervention, participants showed significantly decreased neural activity in several frontal, limbic, and temporal brain regions while watching themselves compared to another musician. Consistent with our hypothesis, we found a decrease in activity related to emotional arousal and anxiety; the most significant decreases were found in the left inferior and middle frontal gyri as well as the left superior temporal gyrus. We also observed decreased activity in various regions involved in attention as well as mental representations of movement.

First, there were decreases in activity within several prefrontal regions that belong to the dorsal and ventral affective systems: the left superior, right middle, and left middle frontal gyri within the dorsal affective system, as well as the right opercular inferior and left inferior frontal gyri within the ventral system. While regulating emotional responses and re-orienting attention, dorsolateral and ventrolateral regions of the prefrontal cortex, including these regions, are commonly activated (Guendelman and colleagues, 2017; Malinowski, 2013). In the contexts of threat appraisal and socio-evaluative anxiety such as MPA, alterations in dorsal affective system activity are common (Britton and colleagues, 2011; Dolcos & McCarthy, 2006); this system allows stimuli to be perceived via appraisal and reappraisal processes (i.e., consciously changing one's interpretation of the stimulus or its relevance to oneself). The ventral affective system is involved in the regulation of emotions (Britton and colleagues, 2011) and is also commonly influenced by threat bias. The pre- to post-intervention decrease in superior and middle frontal gyrus activity may suggest that, following the intervention, participants did not make as many threat appraisals while watching themselves perform. Due to this, they may not have relied as heavily on emotional regulation and attentional re-orientation processes, due to their use of BMM skills (such as inclusive awareness) during the performance and in their daily lives. This is consistent with themes of *Expansive awareness free from judgment* that emerged, and with findings from Hong and colleagues (2024) and Zhang and colleagues (2023) where mindfulness training led to reduced activity in the superior and middle frontal gyri, respectively. Relatedly, the middle frontal gyrus has been shown to be involved in musical imagery (Davidson-Kelly and colleagues, 2011). Following BMM, participants may have devoted less attention to predicting their upcoming movements and notes played. This effect may have arisen from increased confidence in their playing.

Furthermore, there were pre- to post-intervention reductions in left insula activity, which belongs to the ventral affective system. Dysfunction in the insula (anterior insula specifically) can lead to increased anticipatory emotional responses toward a given stimulus (typically negative; Grupe & Nitschke, 2013). BMM training may have decreased anticipatory anxiety toward watching one's own performance video. Left anterior cingulate cortex (ACC) activity also decreased from pre- to post-intervention, another region within the ventral affective system. This may indicate a reduced need to regulate emotional responses, as the ACC (particularly the ventral region of the ACC) is involved in implicit emotion regulation, or the processing of emotion outside of one's awareness, still while subjectively encoding stimuli (Guendelman and colleagues, 2017). The insula, ACC, and anterior PFC are also nodes of the salience network

(SN), which is involved in detecting stimuli that are most relevant (Hasenkamp and colleagues, 2012).

Taken together, the reduced activity in prefrontal and limbic regions following BMM indicate decreased emotional arousal while participants watched their videos, and consequently, a lower need to modulate such arousal and redirect attention. Such patterns have been found in studies of mindfulness; for example, Lutz and colleagues (2014) found that high trait mindfulness was inversely related to brain activity underlying emotion regulation. Individuals with high trait mindfulness may thus rely less heavily on emotion regulation to reduce arousal. Similarly, Goldin & Gross' (2010), found that, following an MBSR course, people with Social Anxiety Disorder (SAD) showed reduced amygdala activity; however, they also showed increased activity in attentional deployment regions while using breath-focused attention to regulate emotions about negative self-beliefs. Boland and colleagues (2025a), which employed the same procedures as in the current study, also found increased activity in attentional and emotional regulation regions following a traditional mindfulness and vocal improvisation program. The pattern of decreased emotional and attentional regulation found in the present study suggests that BMM practice reduced the need for such strategies; specifically, it seemed to reduce arousal in a socio-evaluative context. A potential reason for this is that BMM practices were tailored to the music performance context, whereas other mindfulness techniques, such as those from Boland and colleagues (2025a; 2025b) focus more on adaptive coping when feelings of anxiety arise. As participants in the present study primarily used BMM techniques in a performance context, this may have led to a multifaceted reduction in performance-specific anxiety, thus translating to less emotion regulation during the anxiety-provoking task. Key mechanisms of this effect may include inclusive awareness, reduced tension, and enhanced confidence in movement and playing. Conversely, mindfulness techniques focused mainly on present-moment awareness (e.g., Boland and colleagues, 2025a, 2025b) may engage attentional and emotional regulatory regions, through mechanisms such as nonjudgmental awareness of the moment.

Another substantial pre- to post-intervention change during the anxiety provoking fMRI task was the decrease in left superior and middle temporal gyrus activity. The bilateral superior temporal gyrus has shown hyper-reactivity among people with anxiety disorders compared to controls, for example when listening to emotionally neutral or threat-related words (Zhao and colleagues, 2006). In the context of the present study, these temporal regions likely subserved the process of musicians listening to themselves perform; the superior temporal gyrus in particular is highly involved in music perception (Angulo-Perkins and colleagues, 2014). Participants may have been less hyper-aware of the various auditory elements of the piece post-intervention, perhaps with less anxiety surrounding their listening experience; this would align with themes of *Expansive awareness free from judgment.*

The posterior region of the middle temporal gyrus was also suggested by Davey and colleagues (2016) to be involved in goal-oriented cognition within the DMN. Boland and colleagues (2025b) found decreased functional connectivity between the middle temporal gyrus and the medial prefrontal cortex (mPFC) within the DMN after a mindfulness-based intervention. The decrease in middle temporal gyrus activity may signify that participants required less goal-oriented cognition to regulate potentially ruminative thought patterns.

Furthermore, in Tomasino and colleagues' (2013) meta-analysis, middle temporal gyrus activity was found to be reduced during meditative states. Contrary to our results, findings from Boccia and colleagues (2015) found increased activity in the middle temporal gyrus following a mindfulness intervention, due to its involvement in attentional processes. However, the decrease found in the present study may indicate a different mechanism underlying BMM training, where participants are not actively regulating their emotions and attentional focus while in the scanner. Rather, participants may have developed less of a need for such regulation, as is discussed above.

The left caudate showed reduced activity from pre- to post-intervention as well, which is associated with motor control, threat, reward, as well as self-criticism, and is a supporting part of the salience network (Longe and colleagues, 2010; Peters and colleagues, 2016). This may signify decreased threat appraisal of certain parts of the videos (e.g., mistakes) and thus lower need for attentional refocusing. Having the anatomical insights from the BMM courses and having practiced BMM skills tailored to their needs, participants may have been better able to remain nonjudgmental and present moment focused throughout their videos.

We also found reduced activity in the right posterior cingulate cortex (PCC) from pre- to post-intervention. This is consistent with literature showing that mindfulness training can lead to decreased activation in stress and anxiety processing regions, including the PCC (Monti and colleagues, 2012). The PCC is also a node of the default mode network (DMN; Buckner and colleagues, 2012; Malinowski, 2013; Menon, 2023), a network involved in mind-wandering, rumination, and creative thinking, which can be altered following mindfulness interventions (e.g., Rahrig and colleagues, 2022). The PCC also shows a particular involvement in emotional evaluation (Cabanis and colleagues, 2013), error detection (Foster and colleagues, 2022), and working memory (Maddock, 1999; Maddock and colleagues, 2003; Zhao and colleagues, 2007). Following BMM, participants may have experienced less rumination about performance errors, mind-wandering, and memory processing while watching their video performances. This effect may be owing to reduced self-judgement and increased confidence from the tools provided in the course. Another DMN node, the right precuneus, showed a decrease in activity from pre- to post-intervention. This may also have signified a reduction in self-referential or ruminative thought. Specifically, the posterior precuneus has shown involvement in attributional evaluation, and the anterior precuneus has shown involvement in self-serving processes (e.g., self-serving bias; Cabanis and colleagues, 2013).

A paradoxical element of the decreased precuneus activation is that this region is also involved in spatial mental imagery (Iacoboni and colleagues, 1999) as well as mental representations of the movement of specific body parts (Guillot and colleagues, 2009) and body schema (Lyu and colleagues, 2023); while it would follow that BMM might heighten participants' sensitivity to body-focused mental imagery and movement representations, the training may have decreased their ruminative thought (e.g., involving mental imagery of something going wrong with their performance). Participants may also have experienced fewer mental representations of specific body movements while watching the videos due to being in the process of readapting and remapping of their movement patterns; this idea would align with the adjustment process discussed in association with the theme, *Correction of mismappings promoting free movement*.

The above neural findings are corroborated by results from the anxiety Visual Analog Scale. The 'self' (i.e., own video) condition showed significantly higher anxiety ratings than the 'other' (i.e., control video) condition at both time points, whereas both the self and other ratings decreased significantly from time 1 to time 2. This suggests that participants experienced more confidence while watching themselves perform (and perhaps while performing at the time). It also indicates increased nonjudgmental awareness, both while watching themselves and another musician.

Additionally, a trend that occurred in results from the Anxiety-Provoking task was the left lateralization of brain activity (which was greater pre-intervention than post-intervention). Left hemisphere brain activity has been shown to indicate approach behaviour rather than avoidance, which can involve active engagement with and regulation of emotions (Davidson and colleagues, 2003). Notably, all frontal regions that showed decreased pre- to post-intervention activity were left lateralized. This pattern aligns with the idea of left frontal activity being involved in emotional regulation or cognitive reappraisal in the context of stressful or negative emotional situations (Lee and colleagues, 2025; Papousek and colleagues, 2017). While mindfulness interventions can strengthen such left hemisphere activity through acceptance and coping (Mioduszewski and colleagues, 2020), they can also decrease it, perhaps through quieting this regulation and interpretation of emotions (Gazzanigan and colleagues, 2014). Perhaps the BMM intervention led to a quieting of such regulatory and interpretive activity through reduced tension, expansion of awareness, and increased confidence. Participants may have relied less on cognitive reappraisal while watching themselves perform following the BMM intervention (i.e., less of a need to reframe the experience from a negative threat to a positive challenge).

Brain Activity during the N-back Working Memory Task

From pre- to post-intervention, participants showed significantly increased activity from baseline to post-intervention in brain regions involved in attention, working memory, and sensorimotor processing, in line with our hypotheses. First, we found increased activity in regions involved in motor coordination from pre- to post-intervention: the midbrain, cerebellum, right precentral gyrus, and right postcentral gyrus. Findings from Boland and colleagues (2025a) also revealed that, following a mindfulness-based vocal improvisation intervention, cerebellum and midbrain activity increased during this same task, suggesting improved motor coordination in responding to stimuli (Alexander and colleagues, 1986; Emch and colleagues, 2019) and initiation of motor sequences (Boecker and colleagues, 2008). The cerebellum as well as the precentral gyrus are key nodes of the motor network, which carry out distinct yet interrelated motor functions (Facer-Childs and colleagues, 2021; Marvel and colleagues, 2019). The cerebellum is suggested to be a key region in which internal predictive models of motor control are located, where they are continuously being updated based on actual and predicted consequences of one's actions (Vesper and colleagues, 2010; Wolpert and colleagues, 1995; Wolpert & Ghahramani, 2000). The premotor cortex within the precentral gyrus plays a key role in motor planning processes (Iacoboni and colleagues, 2005; Zatorre & McGill, 2005); specifically, it may generate predictive models of upcoming events in sequential processing, a process that is involved in music (Grafton & Hamilton, 2007; Overy and Molnar-Szakacs, 2009). Similarly, a key node of the sensorimotor network, the primary somatosensory cortex, within the right postcentral gyrus, showed increased activity post-intervention. The postcentral gyrus plays an important role in tactile sensations as well as forming neural representations of body parts

(Ferri and colleagues, 2012). Additionally, the activation of motor regions during the N-back task may have generated internal motor traces to prolong rehearsal of information held in mind (Marvel et al., 2019).

The increased activity within the above-mentioned regions during the N-back task may underline some of the physical benefits of BMM, such as enhanced motor, sensory, and proprioceptive awareness. The influence of BMM on sensorimotor integration and proprioception aligns with themes of *Kinesthetic Awareness, Knowledge of the body's anatomy,* and *Nonjudgmental engagement with sensory stimuli in the periphery of awareness* that emerged during group exploration sessions.

We also found increased activity in right prefrontal regions involved in working memory and attention (middle frontal gyrus, orbitofrontal cortex, medial prefrontal cortex, and dorsolateral prefrontal cortex). Boland and colleagues (2025a) found similar increases in orbitofrontal cortex activity during this task. These patterns may signify improved response inhibition and heightened attention to the letter stimuli (Emch and colleagues, 2019). The intervention's emphasis on training attention, inhibiting maladaptive body movements, and inhibiting negative thoughts during performance may have translated to improved working memory during the task. Corroborating these neural findings, we found an increase in accuracy during the 2-back working memory condition following BMM, suggesting enhanced executive control through mindful body awareness (Ostafin and colleagues, 2015; Stein and colleagues, 2022). However, there were no changes in reaction time. Perhaps a longer BMM intervention period could have led to more extensive changes encompassing both reaction time and accuracy.

Finally, we found an increase in left lingual gyrus activity following the intervention, which is involved in high-level visual processing, including the identification of letters (Bogousslavsky and colleagues, 1987; Kumral and colleagues, 2025). This result runs contrary to Boland and colleagues' (2025a) findings, where lingual gyrus activity decreased from pre- to post-intervention during this N-back task among participants who completed a traditional mindfulness intervention. This pattern of activity in Boland and colleagues' (2025a) research indicated reduced cognitive strain during processing of visual stimuli during the N-back task, and therefore increased efficiency (as was corroborated by reduced reaction times from pre- to post-intervention). BMM participants may have instead engaged the lingual gyrus to a greater degree to help support their improved working memory and motor control. Repeated mindfulness practice has been shown to reduce the effort required to sustain attention (e.g., on visual stimuli) from improved attentional control (Brefczynski-Lewis and colleagues, 2007; Falcone & Jerram, 2018). While BMM may have led to improved working memory and motor control during the task, it may not have increased the efficiency of cognitive processing to as high a degree as more traditional mindfulness-based practices. For example, BMM participants did not complete structured sustained attention practices, like those who completed traditional mindfulness and vocal improvisation interventions (Boland and colleagues, 2025a). Rather, BMM participants completed diverse, tailored self-directed practices over the course of the three weeks.

Themes that emerged from Group Exploration Body Mapping Sessions

During the group exploration BMM sessions, the promotion of nonjudgmental, expansive awareness, correction of mismappings, and efficient breath all promoted a sense of freedom. This is consistent with Conable's original (1998) intention for how BMM can be applied: to promote physical freedom, allowing the musician to embody intelligence for developing musicality.

This freedom was shown to permit smoother, more efficient movements while playing and less muscular tension, which can consequently improve quality of sound and confidence in playing. It also promoted balance, efficient breath, and expansion of awareness. These findings are consistent with previous studies on BMM that found the WEM course to improve playing, physical symptoms of musculoskeletal discomfort, knowledge of body movement, body awareness, and subjective perceptions of performance quality (Bindel, 2013; Buchanan, 2005; Holt, 2016; Knaub, 1999; Rader, 2023; Ross, 2022; Slade and colleagues, 2020).

Based on the themes that emerged, BMM may have implications for reducing MPA. Some key mechanisms for this include enhanced body and breath awareness (Rader, 2023; Salonen, 2018), correction of mismappings and use of support muscles, and knowledge of the body's anatomy (Buchanan & Hays, 2014; Rader, 2023; Ross, 2022). Furthermore, BMM places emphasis on awareness, whether it be awareness of the body, breath, or surroundings; this indicates that it is a form of mindfulness. Through its use of anatomical and somatic education, BMM creates a direct connection between awareness and movement; integrating awareness with movement is crucial for musicians to prevent injuries, achieve high sound quality, and reduce anxiety associated with performance.

Strengths, Limitations, and Future Directions

The present study put forward neuroscientific findings on the impacts of BMM training on MPA, supplemented by subjective measures. This study has several strengths, the first being its mixed methods approach, specifically its use of neuroimaging combined with questionnaire data and qualitative data. Being the first neuroscientific study on BMM, specifically among professional musicians, this study offers mechanistic information on how BMM training influences MPA and working memory, building on the array of BMM studies that employed subjective measures. The empirical basis for the impact of BMM on musicians' well-being may support the use of this approach in music education and performance settings. Considering the straining nature of musical careers, it is important to gather empirical findings on the use of techniques that prioritize musicians' health and well-being.

The present study's repeated-measures approach is another strength, as the literature on the longitudinal effects of mindfulness and somatic interventions on MPA is limited. Furthermore, the brief, accessible nature of the BMM intervention increases its applicability to a wide range of people who experience MPA. Relatedly, another strength is that we incorporated a self-directed component to our intervention, helping evaluate the sustainability and utility of self-directed BMM practice, with the goal to optimize the implementation of BMM techniques.

It is also important to note some key limitations. Our most notable limitation is our lack of a control group. It is therefore possible that familiarity with the session procedures could have played a role in our findings. However, in Boland and colleagues (2025a, 2025b), which used almost identical performance and imaging procedures, the control group showed no difference between time 1 and time 2 in state anxiety nor brain activity (during the same fMRI tasks). These findings suggest that external factors (e.g., familiarity with the sessions, habituation to the MRI scanner) likely did not produce changes in brain activity nor anxiety during our study procedures. Furthermore, our hypotheses were primarily exploratory considering the novelty of the topic and approach, thus results should be considered preliminary. Future studies should build on the current findings, employing a waitlist control group and perhaps an active control condition such as mindfulness, physiotherapy, mental performance or another somatic technique. Such an approach may help to distinguish between the benefits of somatic and mindfulness-based techniques for addressing MPA and further elucidate the impact of combining such techniques in BMM.

An additional limitation is potential variability from the wide age range as well as the higher proportion of female than male participants in our sample. This diversity in age groups is important for an initial neuroscientific study on this topic, as MPA can affect musicians of all ages, and it is important to understand the general effects of BMM among a wide range of individuals. Certainly, future studies should recruit a higher number of participants that permits age group comparisons, to better understand how BMM may differentially impact younger, middle-aged, and older musicians. The neuroimaging analyses also used age as a covariate, so this variable was controlled for in this study. Despite the study's sex distribution being somewhat uneven, the study targeted the population that may benefit most strongly from the intervention (females), as they often show higher MPA (Iusca & Dafinoiu, 2012). It is important that future studies compare sex-specific effects of BMM on brain activity and subjective measures.

Regarding the music played during the lab performance, difficulty of the piece and anxiety associated with the piece should also be controlled for in future studies. Additionally, there are certain limitations to consider regarding thematic results. For example, some participants spoke more than others during the sessions. The sessions were also very diverse in terms of the content covered. However, only codes that emerged across several transcripts were used to create themes.

Finally, the differences in participants' independent practices also presents variability. However, this diversity in individual practices allowed each participant to practice what was the most important for them, using tools that could best address their unique experiences of MPA, playing-related pain, or any other physical or mental concerns impacting performance. Future studies with higher sample sizes should investigate the impacts of different BMM practices in a more fine-grained manner, comparing the neural and subjective effects brought about by specific techniques. Future studies may also wish to include one or more follow-ups with a Licensed Body Mapping Educator during the self-directed practice period. Considering the wide range of practices encompassed within the BMM course, it is important to explore the impact of follow-ups on mental and physical outcomes. For example, a future goal may be to evaluate the most appropriate number of follow-up lessons for individualized BMM practice.

Conclusion

Considering the powerful impact of music on society, it is important to support musicians' physical and mental health. In doing so, empirical data on interventions for improving musicians' health must be collected. In this initial neurophysiological study of BMM, we found promising effects on both a neural and subjective level. Notably, during the anxiety-provoking task, there were reductions in brain activity involved in emotional processing following the intervention. From pre- to post-intervention, we also found increased brain activity involved in sensorimotor processing during the N-back working memory task. These pre- to post-intervention changes may translate to the context of music performance, which relies heavily on focused attention and working memory processes. In line with neurophysiological findings, there were reductions in state, trait, and performance anxiety post-intervention, as well as reduced self-reported anxiety after the anxiety-provoking task and increased accuracy on the working memory task. Finally, thematic results suggested that freedom in movement, breath, and awareness may be mechanisms of these effects. Overall, findings from this study offer initial neuroscientific support for the use of BMM for improving musicians' well-being.

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CHAPTER FIVE: General Discussion

This dissertation put forward an exploratory investigation of how mindfulness-based interventions may improve the well-being of musicians with performance anxiety. These mindfulness interventions included traditional mindfulness as well as vocal and somatic approaches. We employed a mixed methods design to investigate these interventions, incorporating neuroimaging and subjective measures. Our work adds significantly to the literature on musicians' health and well-being, as these repeated-measures studies explored diverse mindfulness practices for this population. Study 1 investigated the effects of a two-week-long Environmental Vocal Exploration (EVE; Oddy, 2022) program and a two-week-long traditional mindfulness program on brain activity during an anxiety-provoking task and a working memory task, as well as on state anxiety; a qualitative analysis of discussion transcripts during EVE sessions was conducted as well. Study 2 examined the impact of these same two interventions on functional connectivity between brain regions during resting state. Finally, Study 3 explored the impacts of a three-week-long somatic intervention, Body Mapping for musicians (BMM; Conable, 1998), on brain activity during the above-mentioned anxiety-provoking and working memory tasks and on state anxiety, music performance anxiety, trait anxiety, trait mindfulness, as well as musculoskeletal discomfort. In addition, a thematic analysis was conducted on discussion transcripts from group exploration sessions in the BMM course.

Overall, results from this dissertation offer initial support for the use of all three kinds of mindfulness-based techniques among musicians with performance anxiety. Alterations were found in brain regions involved in attention, emotion regulation, and sensorimotor integration. Subjective anxiety also decreased among all participant groups. Traditional mindfulness programs may help musicians become aware of their thoughts, emotions, and sensations while performing. EVE may stimulate active coping with performance anxiety through engagement with one's external environment and internal sensations, using the voice and breath as tools. Body Mapping includes diverse techniques that can be personalized to individual musicians, depending on their needs and goals; such practices incorporate movement as well as awareness, breath, and music focus in the contexts of both music practice and performance.

In selecting the most suitable intervention for a musician to try, it is important to consider their unique goals and challenges. If, for example, a musician experiences hypervigilance to sensations of anxiety while playing and is open to trying a variety of mindfulness-based strategies to alleviate such anxiety, traditional mindfulness (e.g., as is practiced in MBSR courses) may be a suitable starting point to offer the musician a sense of grounding, breath focus, and body focus. If seeking a more active coping mechanism to reduce the stress associated with performance, EVE might be a suitable choice. EVE stimulates this active coping by promoting engagement in addition to awareness toward aspects of the body and surroundings. Notably, EVE engages musicians with their community and environments, bringing their focus away from inner feelings of anxiety and towards the world around them. It also fosters a mindful awareness of the body, breath, and voice, allowing a resonance between the self and the space they are playing in. If a musician is struggling with physical tension or limitations that affect performance and mental health (e.g., MPA), fostering a sense of trust in their body and a reduction in tension are crucial. Body Mapping education would thus be a suitable intervention for commencing these processes. Body Mapping promotes adaptive movement and an opening of awareness while performing, which help to free musicians' movement and attentional capacity, so that they are able to focus on more than just one anxiety-inducing stimulus while they play. While the three interventions share the common goal of improving musicians' performance anxiety, they act in different ways. By initiating the study of these interventions, future research may build on our findings, and these interventions may become more widely used in music education, allowing musicians to access tailored interventions depending on their individual concerns.

Pre- to Post-Intervention Changes in Neural Activity

Emotional Reactivity and Regulation

During the anxiety-provoking task, participants who completed the traditional mindfulness program showed increased activity in the precentral, fusiform, lingual, and inferior temporal gyri from pre- to post-intervention. Participants may have been regulating their emotions by inhibiting reactivity and watching the videos with present-moment awareness (Parkinson et al., 2019). Participants who completed EVE showed increased brain activity associated with emotional regulation as well, and to a higher degree than the traditional mindfulness group (e.g., parahippocampal gyrus activation). This indicated active engagement with emotion regulation strategies, such as multifaceted present moment awareness (Boccia et al., 2015; Eisenberger et al., 2003; Laneri et al., 2017; Zeidan et al., 2015; Young et al., 2018). These results align with Hue and colleagues' (2025) findings that MBSR reduced anxiety and improved emotional regulation as well as coping skills in adolescents and young adults. In a performance anxiety context specifically, our findings also align with those of Zhang and colleagues (2025), where mindfulness training helped reduce sports-related performance anxiety, particularly in terms of psychological resilience.

When not engaged in a cognitive task (i.e., during resting state), the EVE group showed decreased functional connectivity between bilateral lateral parietal lobe (LP) seeds within the

DMN and bilateral postcentral gyrus from pre- to post-intervention. Within the postcentral gyrus is the somatosensory cortex, which is involved in emotion regulation strategies (Kropf et al., 2018). This decrease in communication between these regions suggests less coupling of self-referential thought with emotion regulation while not engaged in a task, with EVE participants requiring fewer emotion regulation strategies while mind-wandering in a self-referential manner following the intervention. These modulations of the EVE group's DMN activity from pre- to post-intervention are consistent with themes from EVE discussion transcripts, such as top-down body and breath awareness and increased confidence (Boland et al., 2025a), indicating weakened ruminative thoughts while not engaged in a task. The EVE group also showed reduced resting functional connectivity between bilateral hippocampus and the left postcentral gyrus from pre- to post-intervention, which may signal lower processing of emotional arousal (Chen et al., 2023; Immordino-Yang & Singh., 2011; Northoff et al., 2006).

Consistent with the above resting-state fMRI findings, participants who completed BMM showed a decrease in brain activity associated with emotional reactivity and regulation during the anxiety-provoking task. There was a decrease in left superior temporal gyrus activation, indicating less hyperawareness of the auditory components of the performance videos, and less processing of stress and anxiety (Angulo-Perkins et al., 2014; Zhao et al., 2006). There was also reduced activity in the left superior, right middle, and left middle frontal gyri, which are involved in appraisals of emotional state (Britton et al., 2011; Dolcos & McCarthy, 2006). The insula, anterior cingulate cortex, right opercular inferior frontal gyrus, and left inferior frontal gyrus also showed decreased activation, which are involved in the regulation of emotions, especially in the context of threat appraisals and anticipatory anxiety (Britton et al., 2011; Grupe & Nitschke, 2013). Reduced activation was found in the caudate as well, which is involved in motor control, threat detection, and self-criticism (Longe et al., 2010; Peters et al., 2016). These decreases in brain activity may be related to fewer threat appraisals while participants watched themselves perform. This potential reduction in threat appraisals may have thus led to a reduced need to actively regulate emotions and re-orient attention during the task. It can be inferred that BMM may target ruminative thoughts in a socio-evaluative, anxiety-inducing context specifically, since these changes occurred while participants watched themselves performing. This pattern may arise from BMM addressing both physical and mental components of MPA, thus diminishing the impact of long-standing physical and mental concerns in a performance context.

Following BMM, there was reduced activity in the DMN regions of the right posterior cingulate cortex (PCC), right precuneus, and middle temporal gyrus as well. These findings indicate reduced processing of stress and anxiety (Cabanis et al., 2013; Monti et al., 2012), memories (Maddock, 1999; Maddock et al., 2003; Zhao et al., 2007), body-focused mental imagery (Iacoboni et al., 1999; Guillot et al., 2009; Lyu et al., 2023), ruminative self-referential thoughts (Rahrig et al., 2022), and goal-oriented cognition in the DMN (Davey et al., 2016). After BMM, participants may have experienced less self-judgement while watching themselves perform, including less rumination about body-focused aspects of the performance.

Contrary to the BMM and Mindfulness groups, the EVE group showed increased activity in regions of the salience network during the anxiety-provoking task post-intervention. These regions included the thalamus, caudate nucleus, and insula. Through active engagement with community, surroundings, and sensations, EVE may have trained participants to refocus their attention to other elements of the video when receiving bottom-up signals of emotional arousal (Malinowski, 2013; Menon & Uddin, 2010; Peters et al., 2016; Seeley, 2019). In Mindfulness, simply being aware of these various inputs may have been the crucial element. Similarly, in BMM, the goal is for participants to practice inclusive awareness during the performance, while also moving and breathing adaptively. In EVE, however, a key focus is directing attention to a variety of stimuli (e.g., the sky, the ground, the spaces around you, the people around you).

In alignment with the increased salience network activation following EVE, both the EVE and Mindfulness groups showed increased resting state functional connectivity between the right thalamus and the medial prefrontal cortex (within the DMN). As the thalamus is involved in managing self-referential processing and redirecting attention to the present moment (Jenkins & Mitchell, 2011), communication between the DMN and SN may be a crucial element of these mindfulness-based practices (Rahrig et al., 2022). In the BMM group, however, there was reduced activation in salience network regions (insula, ACC, anterior PFC, caudate), perhaps suggesting less of a need to modulate emotional arousal and redirect attention.

Awareness of Sensory Input

Following EVE, there was increased temporal pole and cerebellum activity during the anxiety-provoking task, which may have arisen from EVE's emphasis on engaging with sensory input, notably auditory and kinesthetic input (Córcoles-Parada et al., 2019; Ito, 2008). EVE may have allowed participants to more easily redirect their attention toward the sensory aspects of their performance videos, and away from ruminative thoughts. EVE participants also showed increased resting state functional connectivity between the bilateral insula and the left inferior temporal gyrus, indicating enhanced body awareness while not performing a task, as the insula plays a role in detecting relevant stimuli, including bodily sensations (Hasenkamp et al., 2012; Hölzel et al., 2011) and the inferior temporal gyrus is sensitive to the impacts of mindfulness (Hölzel et al., 2008; Pickut et al., 2013). On a similar note, Mindfulness participants showed increased activity in the supplementary motor area during the anxiety-provoking task, potentially arising from heightened body awareness (Lhomond et al., 2019).

While not engaged in a cognitive task, the EVE group showed decreased resting state functional connectivity between the lateral prefrontal cortex and both the right middle frontal gyrus and the right postcentral gyrus. Through heightened awareness of sensory input, the EVE group may have required less activity in the right middle frontal gyrus to redirect attention toward sensory aspects of the present moment during resting state (Japee et al., 2015; Vossel et al., 2013; Wang et al., 2025). The BMM group's reduced prefrontal cortex activity during the anxiety-provoking task may also signify increased efficiency in encoding body movement rules (Miller & Cohen, 2001; Overy & Molnar-Szakacs, 2009) from having learned about anatomical foundations of body movement and practicing inclusive awareness of internal and external stimuli.

Sensorimotor Integration during Working Memory

During the N-back working memory task, the EVE group showed increased motor and sensory activation (cerebellum, putamen, midbrain), indicating enhanced coordination in responding to stimuli and inhibiting incorrect responses (Alexander et al., 1986; Boecker et al., 2008; Emch et al., 2019; Mink, 1996). Similarly, following BMM, we found increased activity in the midbrain, cerebellum, right precentral gyrus, and right postcentral gyrus. These brain regions are heavily involved in motor control, proprioception, and also show involvement in planning and predictive processes necessary for working memory (Facer-Childs et al., 2021; Grafton & Hamilton, 2007; Iacoboni et al., 2005; Marvel et al., 2019; Overy and Molnar-Szakacs, 2009; Vesper et al., 2010; Wolpert et al., 1995; Wolpert & Ghahramani, 2000; Zatorre & McGill, 2005). Such effects may arise from multifaceted body, movement, and breath awareness; the adaptive movement taught in BMM may play a role in improving motor coordination as well. The post-BMM increases in precentral and postcentral gyrus activation suggest that, because BMM has a higher somatic focus than EVE, it may have a more profound effect on the sensorimotor network (e.g., Ferri et al., 2012).

Working Memory Processes

Following EVE, participants showed increased middle temporal gyrus and superior orbitofrontal gyrus activation, indicating improved action-feedback monitoring (e.g., van Kemenade et al., 2019) and improved working memory (e.g., Emch et al., 2019), respectively. Following BMM, there was also increased activity in regions involved in working memory, specifically the right middle frontal gyrus, right orbitofrontal cortex, right medial prefrontal cortex, and right dorsolateral prefrontal cortex. These patterns suggest improved response inhibition and attention to the letter stimuli (Emch et al., 2019). EVE may have led to these patterns due to improved executive control, attentional focus, and monitoring, allowing better control and suppression of actions during the N-back task. As BMM focused on training attention and inhibiting movements or thoughts that could be maladaptive during performance, these techniques may also have translated to improved working memory performance, which has important implications for a performance context as well (Pozenatto, 2020; Rayner & Pollatsek, 1997; Schulze and Koelsch, 2012; Sloboda, 1974; Sloboda, 1978).

Attentional Efficiency

Compared to the Mindfulness and control groups, EVE participants showed less activity in regions involved in cognitive processing (middle cingulate gyrus) and visual areas (cuneus, fusiform, inferior occipital gyrus, and middle occipital gyrus) during the N-back task. The mindfulness group also showed less activity in visual areas (bilateral cuneus, lingual gyrus, and superior occipital gyrus) than the control group. These findings suggest that EVE, and to a lesser degree, mindfulness led to reduced cognitive strain during working memory, through present-moment awareness enhancing attentional control; this pattern is consistent with previous findings (Brefczynski-Lewis et al., 2007; Falcone & Jerram, 2018; Koshino et al., 2005; Taren et al., 2017).

Following BMM, this pattern was not found. In fact, we found an increase in left lingual gyrus activity following the intervention, a region involved in high-level visual processing, including the identification of letters (Bogousslavsky et al., 1987; Kumral et al., 2025). Body Mapping, while enhancing sensorimotor aspects of working memory, may not affect efficiency of cognitive processing as much as traditional mindfulness-based practices, such as practices that train sustained attention. BMM participants may have engaged the lingual gyrus more post-intervention with the goal of supporting their improved working memory and motor control.

Following the Mindfulness intervention, N-back reaction times decreased from pre- to post-intervention. This finding is consistent with the mindfulness group developing greater attentional efficiency (e.g., through sustained breath awareness practices). Following BMM, accuracy during the 2-back working memory condition increased, indicating enhanced executive control. No changes were found in the EVE group, though this may be partially accounted for by the lower statistical power for this analysis.

Subjective Changes in Anxiety

Our neural findings suggested divergent mechanisms of anxiety reduction across the three intervention groups. These findings are corroborated by reductions in state anxiety across all groups, regardless of the mechanism through which the reduction took place. However, the time at which state anxiety decreased (i.e., before and/or after performing) varied across groups. Among the Mindfulness and BMM groups, pre- and post-performance STAI-S scores decreased. For the EVE group, only pre-performance STAI-S scores decreased. Both Mindfulness and BMM may have targeted present-moment awareness during times of particularly high anxiety. In the case of the Mindfulness participants, both pre- and post-performance anxiety were likely targeted equally, as there were no significant differences in anxiety between performance condition for this group. For the BMM group, the decrease in post-performance state anxiety was particularly notable (creating a time by condition interaction effect). BMM participants had higher post-performance state anxiety than pre-performance, across both time points; the intervention may have thus targeted this particularly high-anxiety situation.

Among the Mindfulness group, practicing non-reactivity and awareness (e.g., Parkinson et al., 2019) may have modulated their anxiety both before and after performing, perhaps reacting and ruminating less about how they were going to perform/how they performed. Among the BMM group, inclusive awareness (e.g., Buchanan & Hays, 2014; Rader, 2023; Ross, 2022; Salonen, 2018) and tension reduction (e.g., Passarotto et al., 2023; Sokoli et al., 2022), may have played a key role in both pre- and post-performance state anxiety reduction; in particular, participants may have been more confident while playing, leading to less anxiety after finishing their performances. The integration of the body and breath likely played a vital role in this reduction. The EVE group was focused more on engagement with the space, sounds, and sensations a musician experiences before and during a performance; this group may not have experienced as high a post-performance anxiety reduction as the others for this reason.

Additionally, changes in trait-level anxiety (STAI-T scores), as well as performance anxiety (K-MPAI total and domain-specific K-MPAI scores), were not found among the mindfulness and EVE groups. Among the BMM participants, however, there were reductions in trait anxiety, total performance anxiety, and two key domains of performance anxiety from pre- to post-intervention. As the BMM sample was of a larger size than the other two groups, this may have allowed increased power in detecting changes in these often-static constructs. Furthermore, BMM may target more domains of MPA than the other two interventions, notably physical tension, breathing issues, and body movement.

Findings from the anxiety-provoking task were also corroborated by results from the Visual Analog Scale that BMM participants completed right after the anxiety-provoking task (ranging from 1 (extremely relaxed) to 10 (extremely anxious)). First, it can be inferred that the scale accurately captured socio-evaluative anxiety related to the self, as the 'self' condition (i.e., rating anxiety while watching one's own video) generated higher anxiety ratings than the 'other' condition (i.e., rating anxiety while watching the control video) across both time points. Interestingly, both the self and other ratings decreased from time 1 to time 2. Participants may thus have engaged nonjudgmental awareness while watching both themselves and another musician performing, as well as potentially improved confidence in various aspects of their own performances post-intervention. Mindfulness and no-intervention control participants completed the Visual Analog Scale as well; although not a formal assessment, the mindfulness group showed a reduction in anxiety after watching their own videos, while the passive control group showed no changes. This pattern further illustrates the impacts of mindfulness-based interventions on subjective anxiety levels, indicating that these changes likely were not simply due to practice effects.

Themes that emerged following EVE and Body Mapping for Musicians

While themes were not investigated following the traditional Mindfulness intervention, we analyzed themes that emerged in transcripts from both EVE and BMM sessions. Following EVE, themes of both internal and external present-moment awareness emerged, with several subthemes such as community, environment, reciprocity, and breath focus. Following BMM, themes of nonjudgmental awareness, free movement, and efficient breath emerged, with subthemes such as kinesthetic awareness, knowledge of the body's anatomy, reduced tension, and improved breathing efficiency.

Both interventions emphasize body, breath, and sensory awareness. While both draw from mindfulness techniques, they diverge in terms of their mechanisms. EVE uses mindfulness techniques to engage with various aspects of the present moment; this allows active coping with performance anxiety when it arises through the redirection of attention away from the anxiety and toward internal or external aspects of the moment. As EVE uses the voice as a tool for such present moment engagement, the vagus nerve can be stimulated and consequently reduce anxiety (Yuen & Sander, 2017). Body Mapping, however, uses mindful and somatic techniques to reduce tension in the body, a key cause of performance anxiety (Passarotto et al., 2023; Sokoli et al., 2022), and transform it to freedom (Conable, 1998; Griffin, 2021).

General Comparison of the Three Mindfulness-Based Programs

These studies provide initial findings showing that three interventions using different mechanisms may be promising approaches to reducing performance anxiety. This research thus suggests that there are a variety of intervention options for musicians depending on their needs. Overall, depending on a musician's goals and preferences, traditional mindfulness, EVE, and BMM may be useful tools for reducing performance anxiety and improving well-being.

While all interventions were rooted in mindfulness, the three differed in their approaches. Mindfulness focused primarily on awareness, and how tools such as the breath can be used to cope with anxiety; sustained body and breath awareness may also enhance attentional efficiency. This intervention may be most appropriate for musicians seeking grounding and awareness during their performances. EVE focused on methods of engaging with internal and external stimuli when anxiety arises. EVE may be most effective for helping musicians actively cope with anxiety while performing and open their awareness to a variety of stimuli they may have previously ignored, helping regulate anxiety and improve attentional efficiency. BMM also emphasized the opening of awareness, but in the context of playing specifically. It also emphasized adaptive movement and breathing while playing, helping reduce emotional arousal through both guided and self-directed practice. Furthermore, BMM integrated the components of anatomical awareness and movement training into course material. Considering that MPA commonly co-occurs with bodily tension, strain, and breathing difficulties (Passarotto et al., 2023; Sokoli et al., 2022), practicing movement that aligns with one's physical anatomy likely amplified the effect of reduced emotional arousal.

Additionally, both BMM and EVE involved making music in a group, through participants singing as part of EVE practices and through participants playing their instruments together while integrating Body Mapping techniques. The Shared Affective Motion Experience (SAME) model of emotional responses to music proposes that auditory musical signals are heard as intentional, expressive motor acts, which recruit similar neural networks in both the musical agent and the listener (Overy & Molnar-Szakacs, 2009; Molnar-Szakacs et al., 2011; Molnar-Szakacs & Overy, 2006; Molnar-Szakacs et al., 2009). This model suggests that the synchronization of these networks (between the music maker(s) and perceivers(s)) can generate a sense of empathy and social bonding (Overy, 2012). As motivation, affect, and social interaction can act as core components of the musical experience (Overy, 2012), this element of group music making may enhance the effects of EVE and BMM.

Additionally, an important difference between the EVE and BMM interventions is that EVE was created and administered by a single music therapist, whereas BMM Education has long been a part of an association for BMM Educators. The interventions' different development, applications, and history are thus important to consider as we examine future directions for the study of each. Notably, the future outcomes of research on these interventions may differ. For example, future directions for research on EVE may include teaching this technique to other music therapists more widely, and examining different impacts of the intervention when administered by different individuals. For BMM, however, future directions may be to incorporate the preliminary findings from this work and findings from future larger-scale studies into BMM teachings.

Implications and Importance

Considering how important music is to society, musicians' well-being must be supported, in terms of both their mental and physical health. The first two studies of this thesis provide preliminary, empirical findings that EVE and traditional mindfulness training can change the brains of musicians and reduce levels of MPA. To build on this work, an important next step was to emphasize the importance of the body, promoting adaptive movement among musicians while performing music, practicing music, and in everyday life. Alongside violinist and Licensed Body Mapping Educator, Jennifer Johnson, we conducted the third study, which offers initial neuroscientific findings on the effects of Body Mapping on musicians' health and well-being. It has been observed in the Body Mapping Community that musicians suffering from MPA also tend to report an excess of playing-related injuries and muscular tension. Through this research, we can begin to form an empirical basis for the effects of Body Mapping for MPA, which may stimulate larger studies with active control groups on this topic, and lead to important advances in the use of mindfulness-based and somatic practices in music curricula.

The topic of mindfulness-based and somatic practices for improving musicians' well-being is of significance, considering the highly competitive, often stressful nature of musical careers. These studies highlight the need to shape curricula in a way that prioritizes musicians' health and well-being, integrating practices that help musicians use their bodies adaptively, attend to internal and external sensations, and gain confidence in their performance abilities.

As we accumulate neuroscientific, behavioural, and self-reported findings on the effects of mindfulness, vocal-based, and somatic practices for musicians, interventions combining all three elements may be shaped. Such practices could play an important role in fostering confidence and self-compassion among musicians, as they emphasize the acts of awareness toward and caring for one's bodily state. Musicians, commonly adhering to rigorous practice regimens, need these practices more than ever, to ensure that their well-being, enjoyment during playing, and performance abilities are optimized.

Strengths, Limitations, and Future Directions

The studies presented in this dissertation reveal the neurobiological impacts of traditional mindfulness, EVE, and BMM on MPA. The studies have several strengths, the first being that all three added to the limited literature on repeated-measures effects of mindfulness-based and somatic interventions on MPA. The interventions employed were also brief, accessible, and cost-effective, opening them to a wide range of people who experience MPA. The mixed methods approach we used, employing qualitative data, subjective questionnaire data, and brain imaging allowed for thorough and multidimensional investigation of the interventions.

Another strength is that Studies 1 and 2 employed an active control condition (the traditional mindfulness intervention) to compare with the EVE intervention, along with a no-intervention control group. Furthermore, Study 3 allowed high power for neuroimaging analyses through its relatively large sample size. Our studies also allowed examination of both student and professional musicians. As musicians lead busy lives with varying hours, our inclusion of a self-directed practice period for Body Mapping in Study 3 is another strength; self-report data showed that participants' independent practice of Body Mapping techniques ranged from approximately three times per week to several times per day over the self-directed practice period. This work is one of the first studies to investigate the effects of independent practice of Body Mapping techniques and will further knowledge of its sustainability.

There are also limitations to note across all studies, a main one being the small sample size for Studies 1 and 2. These two studies acted as preliminary investigations of EVE's mechanisms in reducing MPA. The significant effects we found indicate that EVE may be a promising technique for reducing MPA and surpass traditional mindfulness techniques in some ways. EVE warrants further investigation in studies with larger sample sizes. Another limitation of Studies 1 and 2 is that some EVE participants were not able to attend all 10 sessions. While all attended at least six, future studies must ensure that participants can attend all of the same sessions and complete the exact same activities. This might also help ensure greater participation from all participants in discussions. Relatedly, another limitation in Studies 1 and 3 is that some participants spoke more than others during group discussions, which were thematically analyzed; however, themes were developed based on codes recurring across multiple transcripts.

Another limitation is the lack of control group in Study 3. It is important to note, however, that Studies 1 and 2 used almost identical procedures and found no differences between time 1 and time 2 for the no-intervention control group's brain activity and state anxiety. These findings suggest that participants were not susceptible to such changes due to external factors, such as familiarity with the session procedures or MRI scanner, or practice effects. Additionally, as this is the first neurophysiological study on Body Mapping for musicians, our hypotheses were mainly exploratory, reducing the need for a control group. Future studies should build on our current findings, employing a waitlist control group as well as an active control condition. Future studies on all three interventions should also ensure randomization of participants to experimental and both active and passive control conditions.

Across all studies, potential variability may have arisen due to the uneven distribution of males and females, with the proportion of females being higher. Females may benefit most strongly from the study interventions since they commonly show higher MPA than males (Iusca & Dafinoiu, 2012). However, given the promising results from these initial studies, future large-scale studies should employ even sex distributions in examining the impacts of these interventions on MPA. The wide age range in Study 3 may have introduced variability as well. Despite this variability, diversity in age groups is important for an initial neuroscientific study on this topic, since MPA can affect musicians of all ages. Future studies with larger sample sizes should aim to recruit evenly distributed numbers of participants in different demographic groups, and conduct comparisons based on age, sex, gender, cultural background, among several other variables; instrument-specific variables would be useful to explore as well, considering the diverging body movements required for different instruments. Variability may also have arisen due to the Study 3 self-directed practice period allowing diversity in participants' independent practices. However, this diversity allowed each participant to practice skills most important for them. Future studies with higher sample sizes should nonetheless build on this initial neuroscientific work to investigate how specific Body Mapping practices impact neural and subjective measures. On a related note, future studies should include participant follow-ups with a Licensed Body Mapping Educator during the self-directed practice period. As the course encompasses a wide variety of techniques, such follow-ups may be necessary to ensure that participants properly grasp concepts and can apply them optimally into their lives.

Aspects of the Anxiety-Provoking Task may also warrant adjustment in future research. For example, participants could play different pieces pre-and post-intervention, to potentially enhance the anxiety provocation. They may also provide different clips for each of the blocks being presented, to allow examination of brain activity during the beginning, middle, and end of the piece. Difficulty of the piece and anxiety associated with the piece could also be controlled in future studies. We set a requirement that participants play something that they had performed in front of an audience at least once before, though this could have still introduced variation in participants' comfort levels with the pieces they performed. Future studies could therefore ask that participants perform a piece they find particularly anxiety-inducing; future work may also compare neural activity during anxiety-inducing versus non-anxiety-inducing pieces.

Finally, to better understand the specific impacts of these interventions on musicians and people in other performing professions, future work may wish to compare the neural and subjective effects of these three interventions among musicians with and without MPA, people in other performance-intensive professions (e.g., dancers, athletes, and actors) with and without performance anxiety, as well as age- and sex- matched non-performing participants from the general public. Follow up for each group of participants would be important to include in future research to identify whether each intervention had long term effects, lasting beyond the time of the study. Future work may also investigate the replicability of these interventions' effects when all three programs are administered by different instructors (i.e., a different Mindfulness Practitioner, Music Therapist, and Body Mapping Educator).

Conclusion

Given the important impact of music on society, we must gather empirical findings on techniques supporting musicians' physical and mental health. Our mixed methods studies put forward initial neuroscientific findings that EVE, Mindfulness, and Body Mapping for musicians may be valuable interventions for musicians with MPA. Mindfulness is not a one-size fits all tool, and this thesis suggests that three different interventions with a foundation in mindfulness may be effective at altering neurophysiology to support reduced MPA. This research lends itself to supporting musicians with different needs but with the common goal of reducing MPA. Through both internal and external aspects of present-moment awareness, EVE may surpass the effects of traditional mindfulness in changing brain activity in regions associated with emotional and attentional regulation. Through freedom of movement, breath, and awareness, Body Mapping reduces activity in emotional processing regions and increases activity in sensorimotor integration regions. Corroborating the neural findings, we found reductions in subjective anxiety following all interventions. Overall, all three studies of this dissertation provide a starting point for neuroscientific investigation of accessible, brief mindfulness and somatic interventions. They offer initial findings that such interventions may improve the well-being of musicians experiencing MPA. As music profoundly enriches our lives, should it not be our responsibility to ensure musicians enjoy making it? This thesis was an attempt to contribute to this goal. As is sung in *Thank You for the Music* by ABBA, "Without a song or a dance what are we?"

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Appendix

Study 1: Thematic Analysis Process

Study 1 and 2: Numeric Results for Nonsignificant Findings (Performance Anxiety)

The 3 (group) x 2 (time) ANOVA results revealed non-significant main effects of time for KMPAI total scores from time 1 to time 2 ($F(1, 23) = 0.785$, $p = 0.385$, $\eta p2 = 0.033$). Interactions between time and group were also non-significant ($F(2, 23) = 0.123$, $p = 0.885$, $\eta p2 = 0.011$).

Study 1 and 2: Participant Intake Questionnaire

Identifiers	
Name	
Email address	
Phone number	
Current City/town	
Alpha-Numeric Codes (for office use only)	
Physical characteristics	
Date of birth	
Gender	
Left or right handedness	
Hand preference: Indicate which hand you habitually use for each of the following activities by writing R (for right), L (for left) or E (for either):	
Writing	
Throwing a ball	
Using a racket	
Striking a match	
Hammering	
Using scissors	
Using a toothbrush	
Participant history	
1. How many years of music lessons have you had?	
2. At which age did you commence studying the piano?	
3. Highest degree of music training attained (degree/RCM certificate/etc.)	
4. Post-secondary education information (current, or most recent): a) Which university? b) Which program? c) Current year of program? d) Which specialization (Performance, musicology/theory, education, pedagogy, etc.)?	
5. Do you play your instrument as an aspect of your career (yes/no)? If so, please explain.	

6. Approximately how many hours per week did you spend practicing/playing your instrument within the following age ranges: a) Child (12 years and under) b) Adolescent (13 to 18 years) c) Young Adult (19 to 24 years) d) Currently	
7. Do you participate in any fitness/physical activities such as sports, etc.? If so, which activity(ies), and how frequently?	
8. If you have experience with any mindfulness-related activities, please answer the following: a) What type? (yoga, meditation, mindfulness-based stress reduction, prayer etc.) b) At what age did you start this/these activity(ies)? c) For how long did you continue to participate in this/these activity(ies)? d) Do you currently participate in this/these activity(ies)? e) How much did you participate in this/these activity(ies) in the past? If you currently take part in mindfulness-type activities, how many hours a week do you typically spend on them?	
9. Which option best describes your performance frequency over the past year? a) More than twice a week b) One per week c) A few per month d) One per month e) A few every six months f) One over the course of the year g) none	

10. Do you use any of the following substances to cope with your performance anxiety: alcohol, marijuana, beta blockers?	a) Yes b) No
11. Have you sought professional help for any psychological conditions in the past? If yes, what was the reason you sought help?	
12. Have you been diagnosed with a psychological disorder (bipolar, depression, anxiety etc.)? If so, which one? Are you currently using medication related to your diagnosis?	

13. On the following scale, indicate your average level of anxiety during your last five performances:

extremely anxious

not at all anxious

Study 1 and 2: Magnetic Resonance Imaging (MRI) Safety Checklist

To assess whether it is safe for you to have an MRI scan we need to know about any metal objects you may have in or on your body, therefore please complete the following: questionnaire.

	Yes	**No**
1. Do you have or have you EVER had a cardiac pacemaker?		
2. Have you EVER had heart surgery?		
3. Do you have any aneurysm clip(s) in your head?		
4. Do you have a hydrocephalus shunt?		
If YES, is it a programmable shunt?		
5. Have you had any operations on your head, brain, eye(s) or spine?		
6. Have you EVER had metal dust/fragments go into your eye(s)?		
7. Have you EVER sustained any metal injuries to any other part of your body (e.g. shrapnel, bullets, pellets)?		
8. Have you EVER had any other type of electronic, mechanical or magnetic implants? (e.g. cochlear implant, neurostimulators, drug infusion pump)?		
9 Have you EVER had any operations involving the use of metal implants, plates, pins, clips or stents including gastric bands or breast tissue expanders?		
10 Have you had any operations on your body in the last 8 weeks?		
11. Do you have any kidney problems?		
12. Have you had or are you waiting for a liver transplant?		
13. Have you ever had a previous reaction to an MRI contrast agent?		
14. Do you suffer from blackouts or epilepsy?		
15. Do you have ANY piercing, hearing aids or dentures? If Yes, please remove.		
16. Do you have any medication patches, tattoos or permanent eyeliner?		
17. Do you wear glasses? If so do you have contacts? Can you see a license plate on a car that is stopped in front of you at a light without your glasses?		

Female participants only:		
18. Are you, or is there any chance you might be, pregnant?		
19. Are you breast-feeding?		
20. Do you have an Intrauterine Contraceptive Device (IUD)? What make?		

Study 3: Thematic Analysis Process

Study 3: Numeric Results for Nonsignificant Findings (Trait Mindfulness, Musculoskeletal Discomfort)

Paired-samples t-tests did not reveal significant changes in Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) scores from time 1 (M = 110.04, SD = 158.88) to time 2 (M = 100.98, SD = 140.64), $t = 0.288$, $p = 0.776$, $d = 0.060$.

Results from the Mindfulness Attention Awareness Scale (MAAS) did not show a significant change in mindfulness from time 1 (M = 56.82, SD = 12.79) to time 2 (M = 55.26, SD = 10.17), $t = 1.029$, $p = 0.314$, $d = 0.215$.

Additionally, there was no significant change the Mindfulness for Musicians questionnaire scores from time 1 (M = 46.91, SD = 5.68) to time 2 (M = 47.30, SD = 5.55), $t = -0.404$, $p = 0.690$, $d = -0.084$.

Study 3: Initial Screening Form (Includes some demographic and health questions as well as the Magnetic Resonance Imaging (MRI) Safety Checklist)

Study Title: Body Mapping and Mindfulness for Musicians' Overall Wellness

<table>
<tr><th colspan="2">Identifiers</th></tr>
<tr><td>Name</td><td></td></tr>
<tr><td>Email address</td><td></td></tr>
<tr><td>Phone number</td><td></td></tr>
<tr><td>Current City/town</td><td></td></tr>
<tr><th colspan="2">Demographic and Health Questions</th></tr>
<tr><td>Age</td><td></td></tr>
<tr><td>Left or right-handed? If hesitation: Which hand do you normally write with?</td><td></td></tr>
<tr><td>Do you play your instrument as an aspect of your career (yes/no)? If so, please provide some more details on how you play professionally.</td><td></td></tr>
<tr><td>Do you currently experience music performance anxiety? Have you ever experienced it?</td><td></td></tr>
<tr><td>How often have you performed over the past year?
Circle one:
h) More than twice a week
i) One per week
j) A few per month
k) One per month
l) A few every six months
m) One over the course of the year
n) none</td><td></td></tr>
<tr><td>Have you heard of Body Mapping before you were notified of this study?
Have you done a Body Mapping course? - Instant exclusion (if they did the full course)</td><td></td></tr>
<tr><td>If you have experience with any mindfulness-related activities, please answer the following:
f) What type? (yoga, meditation, mindfulness-based stress reduction, prayer etc.)
g) At what age did you start this/these activity(ies)?</td><td></td></tr>
</table>

h) For how long did you continue to participate in this/these activity(ies)? i) Do you currently participate in this/these activity(ies)? j) How much did you participate in this/these activity(ies) in the past? If you currently take part in mindfulness-type activities, how many hours a week do you typically spend on them? **Depending on responses: ask for more details and determine afterward how extensive such activities were.**	
Do you use any substances to cope with your performance anxiety, such as alcohol, marijuana, beta blockers, benzodiazepines (i.e., minor tranquilizers), and atypical antipsychotics (i.e., major tranquilizers)?	c) Yes d) No
Have you sought professional help for any psychological conditions in the past? If yes, what was the reason you sought help?	
Do you currently have any diagnosed mental, neurological, or physical health conditions (e.g., a mental health condition such as depression, a neurological condition such as ADHD, or a physical health condition such as diabetes)? **i. If neurological, exclude** Are you currently using medication related to your diagnosis? [**If NOT DIAGNOSED** but they have symptoms/are not sure if they have a given condition or not, ask if they are currently taking a medication for this condition.] i. [If YES (i.e., prescription medication): **may include or exclude depending on medication and condition– e.g., exclude if they are taking ADHD medication**] ii. If they are self-medicating, see what they are using and **exclude if need be** (e.g., cannabis).	

Do you have any back issues that would prevent you from lying relatively still for a 45 minute MRI scan? **Instant exclusion**	
Are you currently taking any medication? If so, can you please provide the type of medication, reason for consumption, the length of time you have been taking it, and the dose of the active ingredient(s) if you know this information?	
Have you ever consumed alcohol? Do you currently consume alcohol? If so, how frequently? Have you ever had a time when alcohol caused significant problems for you? **Instant exclusion**	
Have you ever consumed cannabis, containing either THC, CBD or both? Do you currently consume cannabis? If so, in what form and how frequently? **Level of use**: **1**=never used or 1X total, **2**= 2X total to 10X/1mo period, **3**=more than level 2 **(overall, they cannot be a regular user – e.g., 1x/wk/mo)** *[IF LEVEL 2 OR 3 FOR ANY, EXCLUDE]* [if they only use cannabis once a month or so, ask "is it possible for you to abstain while going through the study?"] Have you ever had a time when cannabis caused significant problems for you? **Instant exclusion**	
Have you ever used any other drugs (like cocaine, shrooms, etc.)? If so, which drug(s) and how frequently did you use it/them? Have you ever had a time when the drug(s) caused significant problems for you? **Instant exclusion** ***(Repeat for each drug listed)*** **Level of use**: **1**=never used or 1X total, **2**= 2X total to 10X/1mo period, **3**=more than level 2 **(overall, they cannot be a regular user – e.g., 1x/wk/mo)** *[IF LEVEL 2 OR 3 FOR ANY, EXCLUDE]*	

Do you have any visual or hearing impairments? Please explain if so. **Instant exclusion if there are any notable impairments (including if they need a hearing aid, since this is an MRI contraindication).**	

Magnetic Resonance Imaging (MRI) Safety Checklist

To assess whether it is safe for you to have an MRI scan, we need to know about any metal objects you may have in or on your body, so we will be asking various MRI safety questions now.

Name:		
Year of birth: **Age:** **Height (cm):** **Weight (kg):** **Pronouns:** **Sex:**		
	Yes	**No**
Prior MRI examination? If yes, record anatomical region, month, year, and hospital/site. Details:		
Any difficulties during previous MRI examination?		
History of prior radiation exposure within the past 12 months, specifically CT scans, Radiation Therapy, Nuclear Medicine and/or PET scans? **Could you please provide more detail on this?**		
Are you claustrophobic? **If yes, instant exclusion.** **If they hesitate: "you seemed to hesitate – could you tell me a bit more about whether or not you might be claustrophobic? Please note that if you have any difficulties being in confined spaces, the MRI is a narrow tube where your body goes in to about your hip, and the device that takes the brain images goes over your face with about 5 inches (or 12 cm) between it and your face, so claustrophobia is a really important criterion."**		
1. Do you have an implanted device, like a pacemaker, defibrillator or any auditory Implants? **Instant exclusion**		
2. Have you **EVER** worked with metal? Have you **EVER** sustained any metal injuries (e.g. getting metal in your eye while working with metal, shrapnel, bullets, pellets)?		

If yes: **Could you please provide more detail on this?** Do you have an x ray on the part of your body that sustained that injury? If so, request & upload x-ray of affected area when booking or ask if they would be able to get the x ray before the study sessions. **Say:** We just can't let anyone in scanner if we think they have metal in their body and the magnet would cause metal to move. Request/upload the report. Details:		
3. Have you **EVER** had any surgeries or invasive procedures of any kind? If so, what type & when? **(e.g., for my info: heart surgery, aneurysm clips in head, hydrocephalus shunt - programmable or not, electronic, mechanical, or magnetic implants like cochlear, neurostimulators or drug infusion pumps; metal implants, plates, pins, clips or stents including gastric bands or breast tissue expanders)** If yes: **Could you please provide more detail on this? Depending on what it is, say:** Please request/upload surgical report(s). Are you planning to have any operations in the next month or two? If yes: **Could you please provide more detail on this?** Do you have any other metal devices in your body, such as braces or permanent retainers? **(other examples: screws, pins, plates, joint replacements, pumps, prostheses, neuro or spinal cord stimulators, clips, coils, stents)** **Could you please provide more detail on this?** Request/upload surgical report(s) (not for orthodontic/dental hardware or orthopedic implants) outlining procedure performed, date, make, model and type of implant. **If permanent retainer**, **ask if they know the material and whether they could please find out from their orthodontist who did the procedure).**		
4. Do you suffer from blackouts or epilepsy? Have you ever had a concussion where you lost consciousness?		
5. Do you have **ANY** piercings, hearing aids or dentures? If Yes to piercings or dentures, say: please remove them for the MRI sessions. **If yes to hearing aids: Instant exclusion since listening to sound is required for an fMRI task**		
6. Do you have any medication patches, tattoos, fake eyelashes, microblading on your eyebrows or permanent eyeliner? If Yes to medication patches, note that medicine patches can lead to skin burns so must be removed prior to examination. If Yes to permanent makeup, fake eyelashes, microblading, etc: request/upload ingredient list to rule out iron oxide.		

If Yes to tattoos: **Did you get it less than two weeks ago?** If yes: ask when was it done, what is the ink color, size, and location? Are you planning to get a tattoo in the coming months? If yes, please note that it is not permitted to go into the MRI scanner with a tattoo that you've had for 2 weeks or less.		
7. Are you planning to have a colonoscopy or endoscopy in the coming months? **Could you please provide more detail on this?** Please note that you cannot have these procedures done within **six weeks** prior to the MRI scan.		
8. Are you currently positive for any antibiotic resistant organisms: MRSA, VRE, C.diff, E.coli? (Methicillin-resistant Staphylococcus aureus, Vancomycin-Resistant Enterococci, Clostridium difficile, Escherichia Coli)		
9. Have you ever tested positive for any antibiotic resistant organisms?		
10. Have you ever been treated or tested positive for tuberculosis?		
11. Have you been in close contact with anyone who has active tuberculosis?		
12. Do you have or have you ever been treated for any of the following: pneumonia, meningitis, encephalitis or Respiratory Syncytial Virus (RSV)?		
13. Prescription Eyewear? If yes, please provide prescription Sphere for the right and left eyes: Right_______________Left____________________	**Note to tell participants if they wear prescription eyewear:** Please note that **MRI safe eyewear** is available only in certain prescription strengths (between -/+2 and -/+7). **Contact lenses** are	

	also safe to wear in the MRI scanner. **Coloured contact lenses**, however are MRI unsafe and not permitted.	
Female participants only:		
14. Are you, or is there any chance you might be, pregnant?		
15. Are you breast-feeding?		
16. Do you have an Intrauterine Contraceptive Device (IUD)? If yes, please record make and model into Comments section. Note: Inform participant that Copper IUDs are MRI conditional as there is a small risk of shifting, potentially affecting efficacy (therefore it may need to be checked medically after).		

Important Note: If the participant answered **YES** to questions 1-3 or 14-16, we **MUST** provide the details in the box below.

Details:

Conclusion: Thank you so much for your time and we will be in touch with you soon to confirm whether you are eligible for the study. Do you have any questions before we end the call?

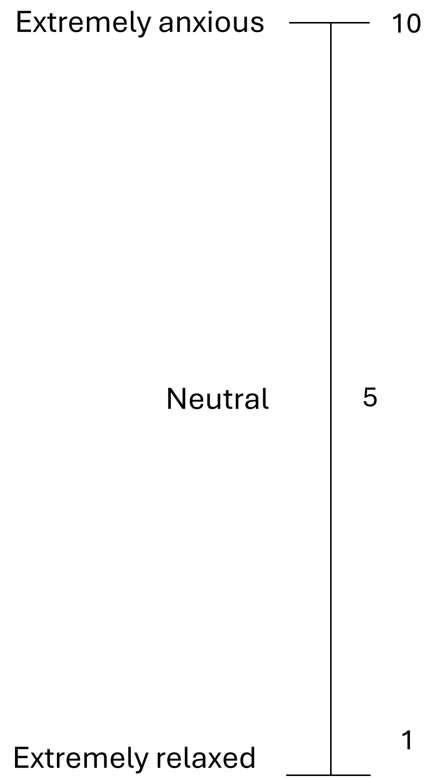
If a participant is deemed ineligible based on any question responses throughout the call: thank them for their time and ask if they would like to be contacted for future research.

***Note*:** In the Demographic and Health Questions section of this Screening Form, questions that do not indicate any inclusion/exclusion criteria beside them are for our information, as exclusions based on these questions can sometimes be made on a case-by-case basis (e.g., excluding people who do not perform regularly). In the Magnetic Resonance Imaging (MRI) Safety Checklist section of this Screening Form, questions that do not indicate any inclusion/exclusion criteria beside them are for the MRI technologists' information. When doing the formal screening, they require the answers to these questions to confirm whether it is safe for the participant to undergo MRI scanning (e.g., medication list, information on surgeries, metal implants, etc.).

Study 3: Demographic Questions

Gender	
Hand preference: Indicate which hand you habitually use for each of the following activities by writing R (for right), L (for left) or E (for either):	
Writing	
Throwing a ball	
Using a racket	
Striking a match	
Hammering	
Using scissors	
Using a toothbrush	
Participant history	
1. How many years of music lessons have you had?	
2. At which age did you commence studying your instrument? At what age did you commence professionally playing this instrument (e.g., freelancing)?	
3. Highest degree of music training attained (degree/RCM certificate/etc.)	
4. **Post-secondary education information (current, or most recent):** a) Which university? b) Which program? c) Current year of program (if applicable)? d) Which specialization (Performance, musicology/theory, education, pedagogy, etc.)?	
5. Do you participate in any fitness/physical activities such as sports, etc.? If so, which activity(ies), and how frequently?	
6. Have you ever experienced an injury associated with your music playing (e.g., pain, strains, tingling, weakness, tension, breathing difficulties, tendonitis, carpal tunnel syndrome)? If so, please provide a brief description of each music playing-related injury you have experienced.	

7. On the following scale, indicate your average level of anxiety during your last five performances:



All studies: Resources

Should participation illicit discomfort, resources are listed here and include 24-hour crisis lines.

1) Mental Health Crisis Line: 613-722-6914, and

2) Ottawa Distress Centre 613-238-3311 http://www.dcottawa.on.ca/, chat and text crisis support