Music on the Brain: Examining the Relationship Between Music Performance Anxiety, Mindfulness, and Brain Activity

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Abstract

Music performance anxiety (MPA) is a debilitating condition affecting musicians at all levels. It has cognitive, physiological, and behavioural implications and greatly affects musicians' professional and personal lives. Although there are studies that have documented mindfulness' effects on MPA, no study has examined the relationship between brief mindfulness training and the neurophysiological, psychological, and behavioural effects of MPA, offering a more comprehensive picture. Indeed, using fMRI provides an objective view of the effects of mindfulness on the wellbeing of musicians with MPA. In the current study, mindfulness demonstrated positive psychological, neurophysiological, and behavioural effects in musicians with MPA. Brain regions related to attention and emotion regulation are thought to underly these findings. For example, in Study 1, a social-evaluative anxiety-provoking fMRI task was used to examine the neural activity and subjective anxiety levels associated with mindfulness training in musicians with MPA. This study found that brief mindfulness training led to increased activity in areas related to attention and emotion regulation, and subjective anxiety levels decreased from pre- to post-mindfulness training in the mindfulness group. For Study 2, a commonly used working memory task, a letter n-back task, was used to measure the neurophysiological and behavioural indices of working memory associated with mindfulness training in musicians with MPA. Results from Study 2 showed decreased neural activity in brain regions related to attention and faster reaction times in the mindfulness group at time 2. Finally, for Study 3, neural activity was measured at rest (resting state) in musicians with MPA who underwent brief mindfulness training and found decreased resting state functional connectivity between areas related to emotion regulation. This study demonstrates the association between brief mindfulness training and MPA via neural, psychological, and behavioural indices. These findings will be beneficial for

musicians' wellbeing and quality of life, as brief mindfulness training is an accessible and cost-efficient way to keep musicians playing the music we all love to listen to.

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Contributions of Authors

I, Kayla Boileau, confirm that I am responsible for the conceptualization and preparation of the project, data collection, data analysis, and writing of this thesis. My thesis supervisor, Dr. Andra Smith, was involved in all of the abovementioned processes. My co-author, Nicole Stanson, was pivotal in the preparation and data collection for this thesis. Dr. Kheana Barbeau and Umara Hansen supported this project throughout the data collection. Dr. Zhuo Fang played a key role in analyzing the data, and Dr. Gilles Comeau assisted in the conceptualization of the project. Each co-author was integral in providing feedback to the manuscripts.

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CHAPTER ONE: General Introduction

Performance anxiety occurs across a wide range of contexts, including test taking (von der Embse et al., 2018), public speaking (Pull, 2012), acting, sport, and music performance, particularly when an evaluative component is present (Rowland & van Lankveld, 2019). Music performance anxiety (MPA) is "the experience of marked and persistent anxious apprehension related to musical performance" (Kenny, 2010, p. 433) and is experienced by 15-70% of musicians at various levels of musical ability (Papageorgi, 2020). MPA is a complex, multifaceted manifestation of cognitive (e.g., decreased concentration, distressing thoughts), physiological (e.g., tachycardia, sweating), and behavioural (e.g., tremor, tensed muscles) responses (Barros et al., 2022; Kenny, 2005). Although a certain level of anxiety is required for peak performance, MPA has been identified as a significant negative issue. The symptoms of MPA can be debilitating, from pre-performance, during the performance, and post-performance, and has profound personal and professional impacts. During the performance, musicians may experience physiological symptoms, such as shaking and hyperventilation, and psychological symptoms, such as memory lapse, negative self-talk, and fear. Musicians also face distressing symptoms before and after the performance, such as decreased attention and increased procrastination, depression, frustration, and substance use (Rowland & van Lankveld, 2019). Indeed, 33.9% of music students use substances to relieve their MPA, and 19% consider abandoning music studies altogether (Orejudo et al., 2018).

Neural Mechanisms of Anxiety

Musicians with MPA attend to external signs of potential threat (e.g., frowns, signs of boredom) and negative internal cues (e.g., fear of negative evaluation, self-imagery; Goldin & Gross, 2010; Osborne & Franklin, 2002). The detection and response to threat is a necessary mechanism of survival; however, those suffering with MPA may exhibit biases in processing potentially threatening information. Whether a musician deems the stimulus as challenging or threatening is determined by their ability to cope with the demands (Lazarus & Folkman, 1984). A musician will deem a stimulus challenging if they are able to cope with the demand. Conversely, a musician will deem a stimulus threatening if it is perceived to outweigh their ability to cope. Appraising a stimulus as challenging, as opposed to threatening, has been associated with lower state anxiety (Trotman et al., 2018) and better attentional control (Moore et al., 2021). Indeed, anxiety has been described as an apprehensive emotional response dependent on the appraisal of a stimulus as threatening (Milne et al., 2019). Individuals with anxiety exhibit threat biases at multiple levels of information processing involving multiple brain regions; however, as there are currently no neurophysiological models of MPA, this thesis will focus on anxiety in general, which is thought to reflect the underlying neurophysiological mechanisms of MPA.

Neurobiological models of anxiety include activity in brain regions related to emotion regulation, such as the orbitofrontal cortex, the ventromedial prefrontal cortex (PFC), the insula, the anterior cingulate cortex (ACC), and limbic structures (including the hippocampus and amygdala). These regions are part of the ventral affective system and are responsible for the threat and reward processing. More specifically, higher-order brain regions, such as the ventromedial PFC, which is responsible for encoding the emotional value of a stimulus and self-based evaluation (Nejati et al., 2022; Suzuki & Tanaka, 2021), and the orbitofrontal cortex, which is responsible for emotional control and maintenance of self-evaluation under threat (Barrett et al., 2007; Flagan & Beer, 2013), regulate emotion-processing brain regions in a top-down manner. This involves "cognitive influences and higher order representations …

[impinging] upon earlier steps in information processing" (Gilbert & Li, 2013, p. 350). Emotion-processing brain regions include the ACC, which is involved in fear processing, and the insula, which is responsible for visceral information processing and introspection related to the emotional experience (Uddin et al., 2017). Limbic structures are also involved. These include the hippocampus, which is involved in negative feedback of the hypothalamic-pituitary-adrenal axis loop (i.e., the main stress response system), and the amygdala, which is involved in processing emotionally salient stimuli and initiating a response.

Brain regions in the dorsal affective system are responsible for appraisals of one's emotional state, including the medial PFC, which is involved in the perception of a stimulus through appraisal and reappraisal (i.e., deliberate change in one's interpretation of the stimulus or its relevance to the self; Britton et al., 2011), the dorsomedial PFC, which is involved in reappraisal of stimuli – especially regarding the regulation of social stimuli (Helion et al., 2019) – and the ACC (Barrett et al., 2007).

Dysregulation of these emotion-adjusting processes is exhibited in anxious individuals, who demonstrate altered functional brain processes. Although MPA is often referred to as a social anxiety disorder, a recent study by Wiedemann et al. (2022) found that generalized anxiety disorder (GAD) is the best predictor of MPA among all major *DSM-5* anxiety types. GAD is characterized by various symptoms, such as persistent and unrealistic worries, fear of negative evaluation, and changes in self-referential processing (Munir & Takov, 2022; Stein, 2015). Considering this, anxiety has been thought to be associated with brain areas related to fear and self-oriented emotion processes. For example, studies have found increased amygdala and insula activation during negative emotional processing (Etkin & Wager, 2007) and increased neural activity in the ACC in response to emotional pictures (Shin & Lizberon, 2010). A negative relationship between the amygdala and ventrolateral PFC – an area thought to modulate the amygdala's response to threat – has also been found (Monk et al., 2008). Increased attentional regulation is thought to underpin these emotion regulation processes (Malinowski, 2013).

Attention

Interest in studying attention goes back 3000 years (Posner, 2016). Its relevance to the human experience has made attention an important focus of psychology. Indeed, in 1908, Edward B. Titchener documented attention as "the nerve of the whole psychological system (p. 173)." We constantly deal with external and internal stimuli, and attention is the cognitive ability that allows us to select and direct our awareness to specific salient stimuli while respecting our cognitive capacity to respond to the stimuli (Morrison & Jha, 2015). Thus, "attention [is] a gate for information flow in the brain" (Cohen, 2014, p. 4).

In psychological research, there are a number of different types of attention, including selective attention and sustained attention, amongst others. Other concepts related to attention include executive control and awareness. Selective attention is when certain information is given priority over other information. In contrast, sustained attention is when focus is given to certain stimuli over a long duration. In a top-down mechanism, executive control determines the allocation of attentional resources, response inhibition (i.e., deliberately refraining from attending to dominant and automatic processes), and response selection (i.e., regulating behaviour by selecting subsequent actions), which are necessary for executing goal-directed behaviour (Cohen, 2014).

In 1990, Posner and Petersen created a model of attention that explains attention via three neural networks, each responsible for a different attentional process and function. However, more recently, functional integration and interaction between these networks has been found

(Fan et al., 2009). These networks include the alerting network, the orienting network, and the executive control network. The alerting network is responsible for alerting us to stimuli and for sustained attention to the stimuli. Brain regions associated with the alerting network include the thalamus, the right frontal cortex, and the right parietal cortex (Malinowski, 2013; Posner & Rothbart, 2007). This system's function is to increase response readiness to stimuli.

The orienting network, sometimes called the selective attention network, directs our attention toward stimuli that have been selected from numerous sensory inputs. The superior colliculus, temporal parietal junction, superior parietal cortex, inferior parietal lobule, supramarginal gyrus, and frontal eye fields are associated with this network (Malinowski, 2013; Posner & Rothbart, 2007; Wadden et al., 2018).

Finally, the executive control network is responsible for detecting and resolving conflicts between competing stimuli. Brain regions associated with this network include the PFC, including the ventrolateral PFC, the basal ganglia, and the ACC. These areas are responsible for executive control processes (Malinowski, 2013; Posner & Rothbart, 2007). It has been suggested that this network is functionally divided further into three networks: the salience network, the default mode network, and the executive control/frontoparietal network.

The salience network consists of the ACC, the anterior insula, and the anterior PFC and is involved in detecting relevant and salient stimuli (Hasenkamp et al., 2012). The default mode network includes the medial PFC, the posterior cingulate cortex, the posterior/lateral parietal cortices, and the parahippocampal gyrus (Buckner, 2008; Malinowski, 2013) and is involved in task negative/stimulus-independent thought, such as mind wandering (Hasenkamp et al., 2012). Finally, the central executive network consists of the PFC and the posterior parietal cortex and is involved in attentional disengagement and in re-orienting or directing attention while maintaining a goal (Hasenkamp et al., 2012).

More recently, Petersen and Posner (2012) updated their attentional model to include metacognitive awareness and self-regulation. Metacognitive awareness, also referred to as decentering, is the conscious awareness of thinking. This conscious awareness helps to counter self-referential processes and activation of the default mode network during mind wandering by directing attention toward the present, temporary moment. Together with attentional control and emotion regulation, metacognitive awareness constitutes a process of improved self-regulation. Self-regulation is "the ability to monitor and modulate cognition, emotion, and subsequent behaviour" (Wolkin, 2015, p. 175), with individuals being able to "differentiate [identifying] these from identifying with them (e.g., awareness that anger is present vs. "I am angry"; Brewer et al., 2011, p. 20254). The inability to decenter and self-regulate may result in psychological distress.

Attention, Emotion Regulation, and MPA

Emotions are changes to the state of an organism in response to the evaluation of an external or internal stimulus (Scherer, 1987). Emotions can be positive (e.g., joy) or negative (e.g., fear), and regulation of emotions is necessary for optimal psychological wellbeing. Emotion regulation creates changes in the length, type, timing, experience, expression, and response to emotions, depending on one's self-regulatory goals (Gross & Thompson, 2007).

A major theory of emotion regulation was developed by Gross (1998), which focuses on five sequential strategies related to the emotion regulation process. The first two strategies, situation selection and situation modification, involve intentionally changing aspects of the external environment, whereas attentional deployment, cognitive change, and response modulation involve changes of attention to external or internal stimuli. One of the strategies is attentional deployment, which is when one directs attention toward or away from the features of the situation (e.g., focusing attention away from threats of negative evaluation). During attentional deployment, selective attention is used to prioritize some features of the situation over others (e.g., signs of boredom). Another strategy is cognitive change, sometimes through reappraisal (e.g. reappraising the stimulus as temporary and separate from the self). Finally, response modulation is directly influencing behavioural components of the emotional response once the emotion is well developed. Sustained attention is used to focus on the stimulus throughout the duration of the emotion regulation model.

Attentional deployment, the third strategy of this model, denotes attentional processes as a core component in understanding emotional responses. As William James (1890) said, “My experience is what I agree to attend to. Only those items which I notice shape my mind - without selective interest, experience is an utter chaos” (p. 402). Information, including information about our emotions, is selected, processed, and analyzed through attentional processes. How then do attentional processes influence our experience of emotions? Gross (1998) identified attentional deployment strategies, such as rumination, which Hayes et al. (2011) have defined as “avoidant concentration.” Rumination is selectively directing attention inwards towards certain emotions (e.g., internal negative emotions) that usually involve past or future events, drawing attention away from the present moment. This strategy has been consistently linked to self-criticism and low mastery (Nolen-Hoeksema et al., 2008) and self-evaluative perfectionism (Dixon et al., 2014).

Attention, Working Memory, and MPA

One of the most studied mechanisms involved in MPA is the relationship between attention and working memory. Musicians utilize long-term, short-term, and working memory in tasks that recruit visual (e.g., reading notation), auditory (e.g., listening to one's own performance), and motor (e.g., using specific fingering patterns) skills, which require high cognitive demand on working memory (Pozenatto, 2020). Although the definition of working memory is highly debated, it is commonly defined as "a cognitive system that actively holds information in the mind to facilitate cognitive operations" (Spencer, 2020, p. 545). Working memory is similar to short-term memory, which is accessing information that is available for only a short period of time; however, working memory encompasses information manipulation. Working memory can be conceptualized as "a short-term storage component with a capacity limit that is heavily dependent on attention and other central executive processes that make use of stored information …" (Cowan, 2008 in Chai et al., 2018).

In the 1970s, Baddeley and Hitch created a working memory model with three components. These components are the phonological loop, responsible for processing and storing auditory information; the visuospatial sketchpad, responsible for maintaining and manipulating visual and spatial information; and the central executive, sometimes called the common attentional control mechanism, which regulates these processes by maintaining goals and decision making in relation to the task, while utilizing attentional processes to accomplish successful working memory functions.

Baddeley also identified other functions of the central executive, including coordinating between multiple tasks (Baddeley et al. 1997), shifting between tasks (Baddeley, 1996), and selectively attending to and inhibiting stimuli (Baddeley et al., 1998). Concordantly, Miyake et al.'s (2000) model of executive control (i.e., shifting, updating, inhibiting) contributes to these working memory mechanisms. Through updating, which is especially important to working memory, individuals actively assess a stimulus' significance and eliminate old, irrelevant stimuli and replace them with newer, relevant stimuli. By shifting, individuals move their attention between tasks, operations, or mental sets (Monsell, 1996). Finally, through inhibition, dominant interfering information is deliberately suppressed.

Musicians frequently outperform non-musicians in auditory, visual, and spatial working memory tasks (Pozzenato, 2020); however, MPA may result in poor attention and concentration, resulting in poorer working memory. For example, as a result of decreased concentration, a musician may be concerned about making a mistake while performing, which leads to distraction and a potential memory lapse (i.e., forgetting the music). Experiencing a memory lapse can then reinforce the musician's concerns about making a mistake. This cyclical process is common in musicians with MPA. Better inhibition, a function of the central executive model of working memory, could help musicians by suppressing salient, and potentially negative, stimuli. In addition, shifting would allow musicians to focus on more neutral stimuli, whereas updating would allow musicians to assess and select stimuli that are relevant to their goals, such as performing a piece well.

To summarize, MPA encompasses various cognitive and behavioural processes, in which attention, emotion regulation, and working memory are fundamental. These mechanisms are essential for performing, highlighting the need for interventions to counter MPA and alleviate its symptoms.

Current Treatments for MPA

Medicinal interventions, such as the use of beta blockers to reduce physiological arousal symptoms of MPA, are common in musicians, with 31% of professional musicians using beta blockers (Kenny et al., 2012). However, these medications only address the physiological symptoms; they do not address musicians' cognitions or behaviours (Steenen et al., 2016). Cognitive Behavioural Therapy (CBT) and, more recently, Acceptance Commitment Therapy (ACT), are the main psychological treatments for MPA. CBT involves cognitive restructuring and behavioural exposure. In comparison, ACT, a "third wave" therapy, requires musicians to accept their emotional distress, rather than mastering or controlling their symptoms, which is central to CBT (Juncos et al., 2017). Results from other third-wave therapies for MPA, such as mindfulness-based therapies, are promising.

Mindfulness

In 1881, the word "mindfulness" first became associated with Buddhism through Rhys Davids' translation of the Pali word "sati" into "mindfulness." However, mindfulness was not a direct translation of sati, as Rhys David described "sati" as "one of the most difficult words … in the whole Buddhist system … to translate" (1910, p. 322). In 1994, Kabat-Zinn operationalized the concept of mindfulness as "paying attention in a particular way: on purpose, in the present moment, and nonjudgmentally" (p .4). This conceptualization of mindfulness has been popularized into the medical tradition through Kabat-Zinn's introduction of the Mindfulness-Based Stress Reduction program (MBSR; Kabat-Zinn, 1982). Since the introduction of this program, use of the term "mindfulness" sharply increased. Since the 2000s, there has been a surge of research studies on mindfulness-based interventions as they became increasingly used for treating various physiological and psychological conditions (Schuman-Olivier et al., 2020).

Mindfulness meditation, which is the practice of self-regulating the mind and body by engaging a specific attentional set (Cahn et al., 2006), is frequently taught in mindfulness-based interventions. This may involve directing and sustaining attention to a thought, disengaging from the thought, and returning attention to the thought, while maintaining non-reactive awareness of the experience.

Types of Mindfulness Training Programs

MBSR is perhaps the most popular and well-known mindfulness-based intervention within the medical field. It is an 8-week program where participants engage in 2 to 2.5-hour weekly sessions. The program is group based and led by a trained practitioner. It aims to relieve stress by learning to attend to the body, emotions, and thoughts in an accepting, nonjudgemental way. Mindful activities in MBSR include sitting meditation, breathing techniques, mindful movement (e.g., stretching, yoga, walking), and body scans. Participants are also encouraged to talk about how to use mindfulness in everyday life and how to handle stressors in a more harmonious way. The efficacy of MBSR to treat anxiety has been well documented, as it has been shown to improve negative self-referencing, emotional reactivity, and trait anxiety (Goldin & Gross, 2010). Indeed, participants in MBSR interventions demonstrated comparable pre-post effect sizes to those in Cognitive Behavioural Therapy when treating anxiety (Hoge et al., 2013).

Despite MBSR's effectiveness, the costs associated with MBSR, such as hiring a practitioner for a long period of time, and accessibility, such as being able to partake in the treatment for 8 weeks, are possible obstacles. Brief mindfulness programs partly address these problems and are shown to be effective in reducing anxiety. For example, a systematic review found that studies employing brief mindfulness programs exhibit positive outcomes in individuals with anxiety (Howarth et al., 2019). In addition, a recent study by de Sousa et al.

(2021) found that state anxiety decreased and state mindfulness increased after only three days in a mindfulness group, but not in an active control group. Together, these studies demonstrate the usefulness of brief mindfulness interventions in reducing anxiety.

How Does Mindfulness Work?

Since mindfulness' inception, many researchers have developed models of mindfulness (e.g., Baer, 2003; Farb et al., 2012; Hölzel et al., 2011; Vago & Silbersweig, 2012), and each model consistently includes one construct: attention. Posner and Petersen's (1990) model of attention, in particular, can help explain the attentional mechanisms behind mindfulness. The alerting network, mentioned above, alerts individuals to an external or internal stimulus and is responsible for sustaining attention to that particular stimulus (e.g., one's breathing) and maintaining awareness of the present moment. When one's mind starts to wander, the default mode network is activated. One will eventually detect that the mind is wandering through involvement of the salience network. The central executive network detects competing stimuli, such as external events, memories, or thoughts about the future, that conflict with one's self-regulatory goals. According to Miyake et al.'s (2000) model of executive control, the central executive network *inhibits* attentional engagement with these stimuli, *shifting* focus back to one's breathing, and *updates* our goals and intentions. Previous studies have supported this model by demonstrating mindfulness' ability to influence attention and attention-related mechanisms in brain regions associated with the alerting, orienting, and executive control networks (Marchand, 2014).

Hölzel et al. (2011) developed a model of mindfulness that takes into account three other distinct but interacting components. These include emotion regulation (including reappraisal), body awareness, and change in perspective of the self. During mindful meditation, the goal is to "[accept] and fully [experience] emotional responses in the present moment without interference from internal thought and self-referent processes" (Taylor et al., 2011, p. 1531). With mindfulness, when an emotional response is elicited, one focuses on internal experiences, including breathing and other bodily sensations. This allows one to accurately identify the emotional response. Emotion regulation strategies, such as reappraisal, allow individuals to experience the emotional response differently. For example, musicians may experience fear about an upcoming performance; however, reappraisal will allow the musician to simply experience the upcoming performance without evaluating the experience as a part of themself.

In this way, with momentary awareness and knowledge that the experience is temporary, individuals can change from relating the information/experience to the self (i.e., self-referential processing) to meta-awareness, or decentering, in which they consciously observe thoughts/feelings as temporary experiences, rather than a reflection of the self (Bennett et al., 2021). This is demonstrated by the finding that brain areas involved in self-referential processing exhibit increased neural activity during negative self-processing, which correlate with decreased social anxiety and increased mindfulness. This suggests greater recruitment of cognitive control mechanisms related to attentional allocation and emotion regulation (Goldin et al., 2012).

Self-regulation is represented throughout this process, and it has been suggested that attention is "the glue that holds together all self-regulatory processes" (Wolkin, 2015, p. 175). This enhanced regulation "keeps the individual within a 'window of tolerance' between hypo- and hyper-arousal, where optimal social functioning and goal engagement is possible" (Chambers et al., 2009, p. 564).

Mindfulness, Generalized Anxiety, and MPA

Anxiety has been conceptualized as a forward-looking phenomenon in which the individual perceives ambiguous stimuli as threatening. Cognitive biases – especially toward socially threatening stimuli – self-focused attention, and subsequent emotional arousal are defining components of the anxiety response. This forward-looking process contrasts mindfulness, which focuses on the present, allows individuals to accurately appraise ambiguous stimuli as non-threatening, and increases mindful attention (Woodruff et al., 2014).

Anxious individuals have tendencies to engage in self-referential processing, which couples the socioemotional content of the past and/or future with the present. This is related to altered neural activity in the default mode network, specifically in the posterior cingulate cortex and precuneus, regions associated with the self (Zhou et al., 2023). This is one suggested mechanism of mindfulness' effects on self-referential processing, which is supported by findings of decreased default mode network activity in the transition from novice to expert meditators (Zhou et al., 2023). Mindfulness is thought to lead to this decentering and emotional disengagement from a salient stimulus (e.g., a threatening thought about the future) through the activation and deactivation of executive control, attention, and emotion regulation brain regions, such as the frontoparietal network, thalamus, anterior cingulate cortex, insula, and amygdala (Zhou et al., 2023). For example, greater activity in the dorsolateral PFC, which coordinates executive control, is associated with less anxiety and is supported by the use of cognitive reappraisal in emotion regulation (Scult et al., 2017). Indeed, individuals with anxiety disorders show less activation in the dorsolateral PFC and dorsal anterior cingulate cortex during reappraisal (Cisler & Olatunji, 2012). In addition, goal-directed behaviour, achieved by shifting attention to relevant stimuli and suppressing attention to irrelevant stimuli, is enabled by the thalamus (Kenwood et al., 2022). However, the insula is responsible for interoceptive and emotional awareness (Sharp et al., 2018), features that are central to awareness of the body – a defining feature of mindfulness – and future-oriented affective responses (Shankman et al., 2014). Both of these brain regions show altered neural activity related to mindfulness. For example, Farb et al. (2013) found increased insular activity after participants underwent 8 weeks of MBSR, and Newberg et al. (2010) found increased neural activity in the thalamus in long-term meditators versus non-meditators. The amygdala is responsible for the "emotional experience and assigning value to neutral stimuli" (Puccetti et al., 2021, p. 3721). The amygdala, part of the fear circuitry, has been shown to be hyperactive in those with GAD (Maron & Nutt, 2018); however, mindfulness induction is associated with decreased amygdala activity in healthy adults (Desbordes et al., 2012) and in adults with social anxiety disorder (Goldin & Gross, 2010).

These neurophysiological findings mirror findings on the cognitive impacts of mindfulness. For example, two weeks of breath-based meditation led to increased concentration and less mind wandering in students studying for the GRE (Mrazek et al., 2013). In addition, working memory and attention were strengthened after only ten hours of mindfulness (Mrazek et al., 2013). Psychological findings, specifically subjective anxiety levels, in musicians with MPA also support the positive effects of mindfulness training. For example, collegiate-level musicians in a cross-sectional study demonstrated that trait mindfulness was associated with lower MPA. They also found that participants who meditated at least weekly reported less MPA (Diaz, 2018). In another study, after 7 weeks of a mindfulness intervention program, Steyn et al. (2016) found that undergraduate music students with MPA who underwent the mindfulness training exhibited decreased state anxiety and increased concentration and self-confidence. In a recent study by Czajkowski et al. (2022), music students underwent 8 weeks of MBSR, and its effects were measured through qualitative interviews. They demonstrated that mindfulness led to increased body awareness, decreased pre-performance MPA symptoms, reappraisal of audiences' reactions, increased mental focus, and less self-judgment after a performance.

Current Study

The neurobiological and psychological mechanisms behind mindfulness have been extensively investigated; however, the neurophysiological effects and underlying mechanisms of mindfulness on MPA are unknown. In addition, the relationship between the neural, behavioural, and psychological effects of MPA are unexplored. Thus, the goal of this thesis was to examine the neurophysiological, behavioural (working memory), and psychological (subjective anxiety) effects of a brief two-week mindfulness training program on young adult musicians with MPA. Attention and emotion regulation models were used to conceptualize the mechanisms behind mindfulness. To achieve this goal, three interrelated studies, divided into three articles, were conducted. For each article, the participants were divided into a mindfulness group or a control group and were scanned using a magnetic resonance imaging (MRI) scanner before and after mindfulness training (in the mindfulness group). Psychological data were also obtained pre- and post-training. Each participant underwent a structural MRI, a diffusion tensor imaging scan, a resting state functional MRI (fMRI) task, a working memory task, and a social-evaluative anxiety-provoking fMRI task. All participants underwent the same scan sequence after two weeks.

fMRI (both resting state and task based) is an excellent tool for providing objective evidence of the impact of mindfulness training on neurophysiological indices of MPA. Many fMRI studies have investigated the neural underpinnings and mechanisms of mindfulness. fMRI has also been beneficial in understanding the neural impacts of mindfulness on studies with anxiety. Although studies have used fMRI in this way, fMRI has not yet been used to examine the neurophysiological effects of mindfulness training on MPA, specifically. Most research on MPA has been subjective; however, neuroimaging may be coupled with subjective measures to provide us with a more objective understanding of mindfulness training on MPA.

Objectives and Hypotheses for the Three Articles

Article 1: Boileau, K., Stanson, N., Hansen, U., Barbeau, K., Comeau, G., Fang, Z., & Smith, A. (Previously submitted to Canadian Journal of Behavioural Science). Validation and use of a social-evaluative anxiety-provoking fMRI task in musicians with performance anxiety who underwent a brief mindfulness training program: A pilot study.

Article 1 had two main objectives: 1) To validate a social-evaluative anxiety-provoking fMRI task in musicians with MPA and 2) to use this task to examine the neurophysiological and psychological effects of this task on musicians with MPA, investigating whether brief mindfulness training would influence these effects. To address objective 1, an anxiety-provoking task with a social-evaluative component was created by recording participants while playing their instrument and using this video to elicit a stress response in the participants while in the MRI scanner. The social-evaluative component comprised two judges who “evaluated” the participants’ performances; this evaluation was also included in the fMRI task. Neurophysiological data from this fMRI task were obtained from 20 musicians with MPA. *Hypothesis 1:* There will be altered neural activity in key stress-related brain regions in response to the task, demonstrating the task’s effectiveness in eliciting a stress response. To address objective 2, the task described in objective 1 was used with the same 20 musicians; however, participants were divided into two groups: a mindfulness group and a control group. The task was used to examine the neurophysiological effects of mindfulness pre- and post-mindfulness training, and anxiety scores were obtained pre- and post-training. *Hypothesis 2:* Stress-related brain areas and areas related to attention and emotion regulation, which are thought to represent the underlying mechanisms of mindfulness, will show altered neural activity in response to brief mindfulness training. Musicians' anxiety scores will also change as a result of brief mindfulness training.

Article 2: Boileau, K., Stanson, N., Hansen, U., Barbeau, K., Fang, Z., Comeau, G., & Smith, A. (In review in Musicae Scientiae). How does brief mindfulness training influence neurophysiological and performance indicators of working memory in musicians with music performance anxiety?

Article 2 had two objectives: 1) To examine the effects of brief mindfulness training on neurophysiological indicators of working memory in musicians with MPA using a working memory task, and 2) to examine the behavioural effects of the mindfulness training using the same working memory task. To address objective 1, participants underwent a common working memory fMRI task, a letter n-back task. Within-group comparisons – neural activity during the n-back task measured pre- and post-mindfulness training – and between-group comparisons – neural activity between the mindfulness group versus the control group at pre- and post-mindfulness training – were examined. *Hypothesis 1:* Mindfulness training will influence neurophysiological indices of working memory, including brain regions related to attention and emotion regulation, in musicians with MPA. To address objective 2, the same working memory task was conducted pre- and post-training, and behavioural indices of working memory (i.e., reaction time and omission and commission errors) were measured. *Hypothesis 2:* Mindfulness training will influence behavioural indices of working memory in musicians with MPA.

Article 3: Boileau, K., Stanson, N., Fang, Z., Barbeau, K., Hansen, U., Comeau, G., & Smith, A. (In press in Psychology of Music). Examining how brief mindfulness training influences communication within the brain of musicians with music performance anxiety: A resting state fMRI study.

Article 3's objective was to measure resting state activity using a resting state fMRI task in musicians with MPA after brief mindfulness training. To address this objective, musicians with MPA underwent a resting state fMRI scan, which required them to close their eyes and not think about anything in particular. This task measured the communication of brain networks as a result of brief mindfulness training, which would help elucidate the mechanisms behind various networks involved in mindfulness, specifically the default mode network. The resting state functional connectivity (rsFC) as a result of mindfulness training was examined in the context of MPA. *Hypothesis:* Mindfulness training will affect the communication of brain regions, including emotion regulation and attention areas, at rest in musicians with MPA.

CHAPTER TWO: Validation and use of a social-evaluative anxiety-provoking fMRI task in musicians with performance anxiety who underwent a brief mindfulness training program: A pilot study

Abstract

Mindfulness may help ease music performance anxiety (MPA); however, there is no research on the neurophysiological effects of brief mindfulness training on musicians during anxiety provocation. Twenty musicians with MPA underwent an MRI scan that included an anxiety-provoking task, in which they viewed videos of themselves performing, of another musician's performance, and of a panel of judges. Ten musicians then participated in two weeks of mindfulness training, while ten did not. All participants completed the same scan sequence two weeks later (time 2). The mindfulness group had greater activity in the dorsolateral prefrontal cortex (DLPFC) than the controls at time 2. Compared to time 1, the mindfulness group demonstrated greater activity post-training in the DLPFC, supramarginal gyrus, inferior parietal lobule, left postcentral gyrus, thalamus, left amygdala, substantia nigra, right superior parietal gyrus, and right postcentral gyrus. This suggests strengthened attention and emotion regulation networks, which may help musicians with MPA.

Introduction

Music performance anxiety (MPA) is ‘the experience of marked and persistent anxious apprehension related to musical performance’ (Kenny, 2010, p. 433), which manifests through cognitions, autonomic arousal, and behaviours (Kenny, 2005). Although a certain level of anxiety is required for peak performance, MPA is debilitating and has been identified as a significant issue as it affects all types of musicians at various levels of musical study (Kenny, 2011). Few studies have focused on the neurophysiological aspects associated with MPA; therefore, one aim of this study was to create and validate a method that researchers can use to infer the neural activity associated with MPA. This task was then used to measure the effectiveness of a brief mindfulness training program in musicians with MPA.

Whether a musician perceives a performance as anxiety-provoking may depend on contextual factors. For example, performing publicly (i.e., in front of judges), as opposed to performing privately, leads to higher state anxiety before and during a performance and altered physiological arousal (e.g., increased cortisol; Aufegger & Wasley, 2018). In addition, an audience does not need to be real for individuals to exhibit these physiological and psychological outcomes (Aufegger et al., 2016). Finally, performing solo, as opposed to performing in a group, is associated with higher MPA (Papageorgi et al., 2011) and is a predictor of more negative post-performance rumination (Nielsen et al., 2017). Taking these contextual factors into consideration, this study created an anxiety-provoking task to be performed in an MRI scanner to assess the neurophysiological correlates of MPA.

Creating and facilitating the task involved several steps, both outside and inside the scanner. It required a musician to perform a solo repertoire, outside the scanner, in front of a panel of judges (research assistants) while being video recorded. The video recording was then used to create the anxiety-provoking task, where the musician was asked to watch themselves play and was told another panel of judges watched their performance (more specific details are provided in the methodology section). This social-evaluative anxiety-provoking fMRI task thus incorporates a public performance and performing solo, contextual factors that are associated with increased MPA.

To relieve MPA, musicians practice coping strategies, such as deep breathing, relaxation methods, mock performance practice, use of medications, and use of recreational drugs and alcohol (Kenny et al., 2014). In fact, a survey by Kenny et al. (2014) documented that to relieve MPA, 31% of musicians reported taking beta-blockers, 12% used alcohol, 5% used anxiolytics, and 4% used antidepressants. In addition, musicians are three times more likely than the general population to use psychotherapy (Vaag et al., 2016). The large percentage of musicians who use medications, alcohol, and/or psychotherapy to relieve their MPA points to the need for coping strategies that could lead to favourable psychological outcomes. Mindfulness, an accessible and cost-efficient practice, may be a solution.

Mindfulness is defined as living with awareness and openness to the present moment without judgment (Kabat-Zinn, 2003). Most mindfulness training involves a core set of practices that enhance: a) the ability to monitor the contents and processes of the mind; b) sustaining attentional focus in the present moment; c) accepting experiences without judgment; and d) psychological distancing/reduction of experiential fusion (i.e., ‘stepping back and observing one’s internal processes of thinking, feeling, and perceiving’; Dahl et al., 2015, p. 517). Through these abilities, mindfulness has been shown to enhance emotional awareness (Phillipot & Segal, 2009) and decrease emotional reactivity in the face of negative affect-producing stressors (Britton et al., 2012). Mindfulness may also facilitate cognitive reappraisal by practicing nonreactivity, promoting cognitive flexibility, and facilitating more adaptive appraisals (Lutz et al., 2015). Increased attentional regulation, a central skill to most conceptualizations of mindfulness, is also thought to underpin increased cognitive and emotional regulation (Malinowski, 2013). These benefits of mindfulness have been shown to have positive impacts on psychological health, including increased subjective well-being, decreased psychological distress, and improved behavioural regulation (Keng et al., 2011). Due to this, mindfulness training, including mindfulness-based stress reduction (MBSR) and mindfulness meditation interventions, has been employed to help alleviate musicians' MPA.

One of the first studies to use mindfulness as a method to reduce MPA was conducted by Chang et al. (2003). In their study, 19 college music students underwent an eight-week mindfulness meditation intervention and were assigned to either a meditation group or a control group. They found that self-reported MPA decreased in the meditation group but not in the control group. Another study examined the effects of meditation and trait mindfulness on self-reported MPA in collegiate music students and found that participants who meditated at least weekly reported less MPA (Diaz, 2018). Research on the effects of mindfulness on MPA has become more frequent, with some studies demonstrating that increased mindfulness is associated with decreased MPA (Czajkowski et al., 2020; Moral-Bofill et al., 2022; Rodríguez-Carvajal et al., 2017). However, the literature more broadly demonstrates mindfulness' benefits through examining its effects on anxiety in general.

Mindfulness interventions, such as MBSR, mindfulness-based cognitive therapy, yoga, and mindfulness meditation, are commonly used techniques to combat anxiety (Hoffman & Gómez, 2017). A meta-analysis conducted by Khoury et al. (2015) examined the effects of MBSR on various outcomes, including self-reported stress and anxiety, and found that MBSR has large effects on stress and moderate effects on anxiety in pre-post analyses in healthy adults. These results were maintained up to 19 weeks of follow-up. Another meta-analysis examined the effects of mindfulness, mindfulness meditation, and yoga on self-reported stress and anxiety in post-secondary students and found moderate effects (Breedvelt et al., 2019).

Although mindfulness has been shown to be effective against anxiety in both musicians and the general population, the neurological mechanisms of mindfulness are unresolved; however, most researchers have suggested a core set of structures that are involved in mindfulness. As previously mentioned, mindfulness is associated with changes in emotion processing. Neurobiological models of emotion processing suggest that the ventral ‘core affective’ system, including the temporal lobe structures (including the amygdala), insula, anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), and ventromedial prefrontal cortex – responsible for the threat and reward system – and a more dorsal affective system, including the medial prefrontal cortex, dorsomedial prefrontal cortex, and the ACC – responsible for appraisals of one’s emotional state – are activated in response to emotion regulation strategies, such as mindfulness (Barrett et al., 2007). Indeed, a recent meta-analysis on the effects of meditation, a common component of mindfulness, on brain function found that compared to control participants, meditators showed greater activation in many frontal, parietal, and temporal regions bilaterally. More specifically, meditation was associated with increased activation in the bilateral middle frontal gyrus, precentral gyrus, ACC, insula, and claustrum. In the left hemisphere, the study found increased activation in the inferior frontal gyrus, precuneus, caudate nucleus, and thalamus, while in the right hemisphere, it found increased activation in the medial frontal gyrus, parahippocampal gyrus, middle occipital gyrus, inferior parietal lobule, and lentiform nucleus (Boccia et al., 2015). There is, however, a limited number of studies that have examined the neurobiological effects of mindfulness on neurofunctional stress reactivity.

The current study validated an anxiety-provoking task in musicians with performance anxiety and used this task to investigate whether brief mindfulness training in musicians with performance anxiety could alter their brain activity in response to a music performance. For the validation, it was hypothesized that the anxiety-provoking task would elicit a stress response and that brain areas related to stress, such as the amygdala and prefrontal cortex, would show increased neural activity in response to this task. Other areas, such as the insula, may also show increased neural activity as it has been found to be active in response to threats toward the self (Hughes & Beer, 2013); whereas, some areas, such as the ACC, may show reduced activity in response to threats toward the self (Hoefler et al., 2015).

For the brief mindfulness training program, it was hypothesized that participants in the mindfulness group would show increased brain activity in areas associated with emotion regulation, such as regions in the prefrontal cortex, and decreased activity in areas associated with arousal and processing negative emotions, such as the amygdala. It was hypothesized that there would be no changes in the control group.

Methodology

Participants

Twenty participants with self-identified MPA between the ages of 18 and 28 (M = 23.4, SD = 2.9) were recruited. Ten participants identified as male, and ten identified as female. The participants played a range of instruments. For the validation portion of the study, all twenty participants were analyzed together. For the brief mindfulness training, participants were allocated to the experimental and control conditions based on date of enrollment in the study.

The first ten participants who registered were allocated to the experimental condition (5 females and 5 males), and the next ten were allocated to the control condition (5 females and 5 males). Participants were recruited by posters located throughout a Canadian university's music building, through convenience sampling via email, and by contacting private music instructors to ask if their students wanted to participate. This study was approved by the Canadian university's research ethics board, and informed consent was obtained from all individual participants included in the study.

The young adult musicians who were included in the study had achieved grade 7 from the Royal Conservatory of Music or had completed or were currently completing an undergraduate or graduate degree program in music. Participants were also included if they had normal or corrected vision and had normal hearing. Participants were excluded if they engaged in any kind of formal mindfulness training currently or in the past or if they were taking medication for any psychological disorders. 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

Prior to experimentation, demographic and health information was collected. This included their age, sex, previous experience with mindfulness activities (e.g., yoga, meditation, MBSR), instrument type, number of years of music lessons, the age at which they commenced studying their instrument, their highest degree of music training attained, and whether they had pre-existing psychological conditions.

Spielberger State-Trait Anxiety Inventory

MPA was measured several times during this study using the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983). The STAI contains two subscales. Only the state subscale was used in the current study. It contains 20 questions in which participants use a 4-point Likert scale to rate how much each statement resonates with how they feel at this moment. Participants answered questions such as ‘I feel at ease’ and ‘I feel strained’ on a scale ranging from 1 (*not at all*) to 4 (*very much so*). A total sum score was computed after reverse-scoring, with higher scores indicating higher anxiety. The STAI has been previously used in studies examining MPA (Brooker, 2018; Spahn et al., 2010) and in studies examining the effects of mindfulness training (La Torre et al., 2020; Vøllestad et al., 2011). The STAI has shown good validity and reliability in previous studies (Julian, 2011). In this study, the state subscale of the STAI demonstrates excellent reliability (pre-training; $\alpha = .93$, post-training $\alpha = .93$).

Procedure

The first step for each participant in this study was to perform in front of a panel of judges. Upon arrival to the performance session, participants were asked to fill out the demographic and health questionnaire. They then completed the state subscale of the STAI and were given 5-7 minutes to warm up using their instrument before being brought to a different room. In front of a jury panel of two individuals, each participant then performed 6-10 minutes of solo repertoire that they had previously performed at least once and had been asked to practice prior to testing. The participants were told that the jury panel would evaluate their performances. In reality, the jury panel consisted of two judges who were told to act like they were evaluating participants’ performances. Each participant’s performance was video-recorded, and this recording was used for the anxiety-provoking task during the fMRI session. After the performance, they completed the state subscale of the STAI once again. Within 6 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 diffusion tensor imaging sequence, a resting state fMRI scan, a working memory n-back task, and the anxiety-provoking task (described below). The experimental group then underwent two weeks of mindfulness training, while the control group was not permitted to practice any mindfulness-like activities throughout the duration of the study. At the end of the two-week training period, all participants took part in post-training data collection identical in structure to the pre-training session. Each participant was asked to play the same piece of music in front of the jury panel at both the baseline and post-training sessions. Within 2 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.

Mindfulness Training

Participants in the experimental condition underwent a two-week mindfulness training program. The program was a condensed version of the traditional eight-week mindfulness training program and comprised ten one-hour sessions over the course of two weeks, with participants required to attend a minimum of six sessions. Each session was taught by a registered Mindfulness-Based Cognitive Therapy facilitator and was conducted in group format. Each session consisted of a variety of meditation, body scanning, breath awareness, mindful walking, qigong, and discussion groups. During the discussion groups, participants were encouraged to talk about 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) throughout the duration of the training.

fMRI Procedure

Participants underwent the 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 anxiety-provoking task was performed during an echo planar pulse sequence, TR/TE 3000/27 ms, flip angle 90^{o}, FOV 24x24 cm^{2}, 64x64 matrix, slice thickness 3 mm, 48 axial slices, bandwidth 62.5 kHz. All participants underwent the same scanning procedure. The results from the other pulse sequences will be presented elsewhere.

Anxiety-Provoking Task Before and After Mindfulness Training

Each participant's video recording of their baseline performance was used to evoke feelings of performance anxiety while in the scanner. While in the scanner, participants were also told that a jury panel of two individuals (also research assistants; 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 judges. During the task, participants were shown a control video (1 minute), followed by a video of the judges reviewing the participants performances (21 seconds), followed by the anxiety-provoking condition (1 minute), followed by another jury video (21 seconds). This sequence repeated three times with 12-second blocks that presented a fixation (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 1-minute video and so on). This was the same for the participant videos and the jury videos. The control videos consisted of viewing sections of a recording of a young adult female musician playing the trumpet. All participants were shown the same jury panel and control condition video. The only difference between participants' imaging experience was the anxiety-provoking condition (watching themselves play their piece). Overall, this task lasted 8 minutes and 42 seconds. See Figure 1 for a flowchart of the task procedure.

Data Analysis

Anxiety-Provoking Task Validation

fMRI scans were pre-processed and analysed with SPM12. Pre-processing included realignment to control for motion, normalization (to the MNI template provided in SPM12), and smoothing (6 mm Gaussian kernel) steps. First-level analyses were performed with the contrasts of interest as brain activity for 1) participant/judging videos minus control/judging videos while controlling for STAI scores and 2) control/judging videos minus participant/judging videos while controlling for STAI scores. Second-level random effects analyses were performed with a one-sample t-test with the STAI scores as a covariate. Analyses were performed at a set threshold of whole brain-level uncorrected $p < 0.05$, with a cluster-level family-wise error (FWE) correction at $p < 0.05$ and a set cluster size larger than 10 voxels.

State Anxiety

The data were screened for outliers in state anxiety (STAI state subscale scores) at every time point. There were no outliers; all participants exhibited some degree of anxiety pre- and post-performance. Pre- and post-performance scores at baseline were averaged to produce one 'baseline' anxiety score. A similar average score was computed for pre- and post-performance at post-training, which is called the 'post-training' score. IBM SPSS (Version 28) was used to conduct a 2 (group: mindfulness and control) x 2 (time: baseline and post-training) repeated measures analysis of variance (ANOVA) to examine any differences in state anxiety between the mindfulness and control groups at baseline and post-training.

Anxiety-Provoking Task Before and After Mindfulness Training

fMRI scans were pre-processed as in the validation part of the analysis; however, the individual contrasts were then included in second-level random effects analyses to compare pre- and post-training activation between groups and also within groups, controlling for STAI scores. Two-sample t-tests were used to compare the groups at baseline (pre-training; first scan) and post-training (second scan), while paired sample t-tests were used to compare pre- and post-training scans within groups. Analyses were performed at a set threshold of whole brain-level uncorrected $p < 0.05$, with a cluster-level family-wise error (FWE) correction at $p < 0.05$ and a set cluster size larger than 10 voxels.

Results

Behavioural and Sociodemographic

There were no significant group differences in sex (5 females and 5 males in each group), age, whether participants had pre-existing psychological conditions, experience with mindfulness activities, age since starting music, number of years of music lessons, and number of hours of practice in adolescence or as a young adult. However, there were differences in the number of hours of practice currently, with the mindfulness group practicing more than the control group, $t(17) = 2.30$, $p = .034$.

Anxiety-Provoking Task Validation

When examining all 20 participants performing the task for the first time, there was a significant increase in activity in several clusters that included the postcentral gyrus bilaterally, the left superior frontal gyrus, the left middle frontal gyrus, including the cingulate gyrus, and the left OFC when watching themselves play when compared to watching someone else play.

The brain was significantly less active watching themselves play when compared to watching someone else play in the left lingual gyrus, the right fusiform gyrus, the right superior temporal gyrus, and the right inferior frontal gyrus, including the inferior operculum (see Table 1 and Figure 2).

State Anxiety

When testing assumptions, Levene's test of homogeneity of variances was not significant, there were no outliers when examining boxplots, and variables had normal distributions according to the Shapiro-Wilk test of normality. The mean anxiety score for all 20 participants at baseline (pre-mindfulness training) was 44.4 (*SD* = 10.8). In addition, the 2 (group) x 2 (time) ANOVA results indicated that there were non-significant main effects of time ($F(1, 18) = 4.10$, $p = .058$, $\eta_p^2 = .185$) and group ($F(1, 18) = 1.01$, $p = .327$, $\eta_p^2 = .053$) and a significant time by group interaction ($F(1, 18) = 11.85$, $p = .003$, $\eta_p^2 = .397$). Post-hoc pairwise comparisons demonstrated that there was a significant difference in anxiety scores between the control group and the mindfulness group at time 1 ($p = .020$) but not at time 2 ($p = .627$). In addition, there was no difference in anxiety scores from baseline to post-training in the control group ($p = .329$; *M*baseline = 39.0, *SD* = 9.1, *M*post-training = 41.7, *SD* = 9.4). However, there was a difference in anxiety scores from baseline to post-training in the mindfulness group, such that the mindfulness group decreased in anxiety scores from baseline to post-training ($p = .001$; *M*baseline = 49.6, *SD* = 9.9, *M*post-training = 39.3, *SD* = 12.6; see Figure 3).

Anxiety-Provoking Task Before and After Mindfulness Training

As shown in Table 2 and Figure 4, from baseline to post-training, participants in the mindfulness group showed increased activity in a large cluster containing the left supramarginal gyrus and left inferior parietal lobule. They also showed increased activity in a large cluster containing the left dorsolateral prefrontal cortex (DLPFC) and left postcentral gyrus. Increased activity in a cluster containing the thalamus, substantia nigra, and left amygdala was also found. Finally, there was also increased activity in a cluster containing the right superior parietal gyrus and right postcentral gyrus.

From baseline to post-training, those in the control group showed increased activity in a large cluster containing left Heschel's gyrus and left cuneus and in another large cluster containing the right precentral gyrus and postcentral gyrus (see Table 2). There were no differences in activity between the groups at baseline; however, at post-training, the mindfulness group showed greater activity in the DLPFC (uncorrected; -32 56 18; $t(1,17) = 5.10$, $p = 0.012$; see Figure 4E).

Discussion

This exploratory study validated an anxiety-provoking task that was used to provide empirical evidence of a significant neurophysiological effect of brief mindfulness training on musicians with MPA. When validating the anxiety-provoking task, significant increases in brain activity were observed when musicians watched themselves play when compared to watching someone else play in regions related to processing sensory information (e.g., postcentral gyrus), self-awareness (e.g., superior frontal gyrus), emotion regulation (e.g., middle frontal gyrus), and self-evaluation under threat (e.g., OFC). This may demonstrate that the musicians had more sensorimotor self-awareness when watching themselves play when compared to watching someone else play. This interpretation is supported by studies that show that the somatosensory cortex and superior frontal gyrus are key areas related to interoceptive attention (Goldberg et al., 2006; Kropf et al., 2019). Musicians also exhibited more neural activity in the middle frontal gyrus, including the cingulate gyrus, and in the OFC when controlling for subjective anxiety scores. In this sample of musicians, every musician had MPA, which may lead to dysregulated activity in areas related to emotion regulation, such as the cingulate gyrus (Blair et al., 2012), and in areas involved in maintaining positive self-evaluations under threat, such as the OFC (Flagan & Beer, 2013). Thus, when controlling for anxiety, areas related to emotion regulation and positive self-evaluation, processes that are normally suppressed and/or dysregulated in individuals with anxiety, may be more active.

While watching themselves play compared to watching someone else play, the musicians exhibited decreased activity in the fusiform and the lingual gyri, which play a role in visual processing (Palejwala et al., 2020), and in the inferior frontal gyrus, which plays a role in inhibitory activity (Aron et al., 2014). Finally, there was decreased activity in the superior temporal gyrus, an area related to auditory processing. Less activity in these regions while watching themselves play may be related to the musicians' familiarity with their own music versus the piece that the control musician played (Freitas et al., 2018). It may also be due to more neural resources going toward the emotional and somatosensory aspects of watching themselves play when compared to watching someone else play.

When examining the musicians' neural activity following the mindfulness training, there were significant increases in activity in brain regions related to attention (e.g., thalamus, right superior parietal gyrus, inferior parietal lobule, supramarginal gyrus, DLPFC, substantia nigra) and emotion regulation (e.g., DLPFC, left amygdala).

Studies have found increased neural activity in those who practice mindfulness in areas related to attention, specifically in areas related to the alerting (being sensitive to incoming stimuli; e.g., thalamus, right superior parietal gyrus), orienting (selecting information from a sensory input; e.g., inferior parietal lobule, supramarginal gyrus, right superior parietal gyrus), and executive (resolving conflict; e.g., DLPFC, substantia nigra) neural networks (Malinowski, 2013; Marchand, 2014; Posner & Rothbart, 2007; Wadden et al., 2018). When practicing mindfulness, one might focus on one's breathing; this sustained attention is achieved via activation of the alerting neural network. When one loses attention and the mind starts to wander, the default mode network is activated. Eventually, one will detect that the mind is wandering, through the involvement of the salience network, and will let go of the wandering thought via the executive neural network. Refocusing on one's breathing is accomplished by shifting attention back to the breathing, which is achieved via activation of the executive and orienting neural networks (Malinowski, 2013).

Increased neural activity was observed in the present study in brain regions implicated in the alerting, executive, and orienting attentional neural networks, suggesting that the brief mindfulness training increased musicians' attentional abilities. Previous studies have demonstrated that musicians split attentional resources between negative internal cues (e.g., fear of negative evaluation, self-imagery) and external signs of potential threat (e.g., frowns, signs of boredom; Goldin & Gross, 2010; Osborne & Franklin, 2002). Meanwhile, mindfulness training has been shown to influence one's ability to exert cognitive control over such negative rumination via increased attentional abilities (Ramel et al., 2004). Thus, the attentional benefits of mindfulness may allow musicians to direct their attention away from any negative thoughts that they may have, allowing them to refocus on their performance.

Emotion regulation refers to the strategies used to influence the length, type, timing, experience, and expression of emotions (Gross, 2007). Practicing mindfulness may directly influence some of these strategies, including attentional deployment (i.e., 'directing attention away from the emotional content of a stimulus'; Gross, 2007, p. 48), cognitive change (i.e., 'altering the subjective meaning and/or perceived self-relevance of the present situation'; Gross, 2007, p. 33), and response modulation (i.e., 'targeting behavioral manifestations of emotions'; Gross, 2007, p. 33). According to Lutz et al. (2008), attentional change as a result of mindfulness training may lead to 'improvement in the capacity to disengage from aversive emotional stimuli … enabling greater emotional flexibility' (p. 166). In order to successfully regulate one's emotions, prefrontal cognitive control mechanisms must be strengthened, which down-regulates neural activity in emotion-processing brain regions, such as the amygdala (Tang et al., 2015). In the present study, there was increased neural activity in the DLPFC, which is consistent with most reviews (Marchand, 2014; Tang, 2015), and in the left amygdala, which is a rare finding in other studies that examined the neurophysiological effects of mindfulness. Most studies have documented decreased activity in the amygdala (Marchand, 2014; Tang et al., 2015). However, the right amygdala is mainly involved in the automatic processing of emotions, while the left amygdala is primarily involved in cognitively controlled emotional processing (Barreiros et al., 2019).

Mindfulness is thought to promote early awareness and non-judgmental acceptance of emotional stimuli, allowing one to regulate one's emotions early on during stimulus processing (Teper et al., 2013). As a result, it is possible that there is a recruitment of brain regions that are sensitive to affective cues that regulate emotions in a controlled (i.e., left amygdala, DLPFC) rather than an automatic (i.e., right amygdala) manner. Amygdala–frontal coupling has been demonstrated during emotion regulation. Specifically, left amygdala activity has been found to covary with DLPFC activity, especially during reappraisal-based control of negative affect (i.e., using the emotion regulation strategy of cognitive change; Banks et al., 2007).

The brief mindfulness training was associated with changes in neural activity in key brain regions involved in attention and emotion regulation. It was also associated with decreases in subjective state anxiety levels. Usually, increased anxiety levels result in one focusing on potentially threatening stimuli above and beyond other stimuli. However, increased attention regulation abilities gained through mindfulness can allow one to *inhibit* attentional engagement with potentially threatening stimuli, *shifting* one's attention back to the object of focus (e.g., one's breathing) when one's mind wanders, thus continuously *updating* one's goals and intentions. These three executive processes are key to attentional selection and control (Eysenck et al., 2007) and can help those with anxiety to overcome the attentional biases that they have toward threat-relevant stimuli (i.e., negative internal and external cues), thereby decreasing their subjective anxiety scores. This relationship has also been found in a previous study that examined the association between mindfulness and perceptions of social threat (Brown et al., 2012). Furthermore, mindfulness training allows one to be aware of the potential threat with non-judgmental acceptance, whereas those without mindfulness training might exhibit avoidant behaviors and thoughts, such as worrying, preventing them from seeing evidence that contradicts their worries and further heightening their threat appraisals in the future (Grupe & Nitschke, 2013).

Although it was hypothesized that there would be no changes in the control group, those in the control group demonstrated increased neural activity in Heschel's gyrus, cuneus, right precentral gyrus, and postcentral gyrus from baseline to the second scan. These regions play a role in visuo-motor (e.g., precentral gyrus, cuneus) and auditory (e.g., Heschel's gyrus) processing and in processing sensory information from various parts of the body (e.g., postcentral gyrus). Since the control participants watched their performances twice, it is probable that they became more critical of their performances the second time, perhaps through sensitization, thus focusing on specific (potentially negative) sensory stimuli. Meanwhile, the mindfulness participants' attentional and emotion regulation abilities gained through the mindfulness training led them to inhibit engagement with the potentially threatening stimuli.

Finally, there was significantly more activation in the DLPFC in musicians in the mindfulness group at post-training when compared to those in the control group. This is important as the DLPFC underlies the attentional and emotion regulation abilities gained through practicing mindfulness (Marchand, 2014; Tang, 2015). This is also important because activation of this brain region has been documented in other studies on the neurophysiological effects of mindfulness, demonstrating that the present study did indeed evoke neurophysiological changes related to mindfulness.

Strengths, Limitations, and Future Directions

This exploratory study provides insight on the neurophysiological effects of brief mindfulness training on musicians with MPA and has many strengths. First, it successfully validated a social-evaluative anxiety-provoking fMRI task that can be used in future studies to measure MPA. Second, it is longitudinal. As noted in reviews on the neurophysiological mechanisms of mindfulness (Malinowski, 2013; Tang et al., 2015), most of the current research is limited to cross-sectional study designs. In addition, this study employed one mindfulness instructor, so all mindfulness participants underwent the same mindfulness training. Its brevity is also a strength. In only two weeks of six or more sessions, the mindfulness training has shown significant neural effects in the musicians. Thus, short mindfulness training programs may offer musicians an efficient method to manage their MPA. Follow up is clearly required to assess if this effect is long lasting.

Despite this study's strengths, there are some limitations. The most significant limitation of this study is sample size. Future studies should recruit larger samples of participants. Another limitation is that participants were not rigorously screened for substance use before their scans. They were simply asked if they used alcohol, marijuana, or beta blockers to help with their MPA with a yes or no answer; therefore, substance use before the scans may have influenced participants' behaviours and emotional responses during their scans. In addition, the study did not randomly allocate participants to the conditions. Some participants may have been more motivated and/or interested in completing mindfulness training than others, so future studies should aim to randomly assign participants to each condition. Ideally, this study would have employed a crossover experimental design, in which all musicians would have undergone the mindfulness training. However, this was not feasible for this exploratory pilot study. Future studies should also use an active control in comparison to the mindfulness condition, which this study did not do. The mindfulness condition required more time from the participants and involved a group format, whereas the control condition required less time and did not involve group participation. Finally, there were differences in anxiety scores between the mindfulness and control groups at baseline. It may be that mindfulness training is more efficacious for those with higher anxiety levels; however, a meta-analysis by Khoury et al. (2013) showed that mindfulness-meditation-based interventions demonstrated decreases in anxiety levels from pre- to post-intervention for clinical and non-clinical mild, moderate, and high-anxiety individuals.

Conclusion

The findings from this pilot study demonstrate that brief mindfulness training activates brain regions responsible for attention and emotion regulation while musicians watch a recording of themselves perform when compared to a stranger performing. Attentional and emotion regulation abilities are crucial aspects of a musician's ability to perform. In addition, the skills gained from practicing mindfulness may impact their overall wellbeing, as MPA may affect musicians' professional and personal lives. Although small, this exploratory study suggests that further research is warranted to investigate the potential benefits of mindfulness training to help with musicians' performance anxiety.

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Table 1

Validating the Anxiety-Provoking Task Controlling for STAI Scores

Comparison	Region	Cluster size (voxels)	MNI Coordinates			*T*	*p*-value
			X	Y	Z		
Participant/judging videos > Control/judging videos	R. and L. Postcentral gyrus	4419	-32	-42	68	7.06	FWE 0.004
			18	-46	76	4.07	
	L. Superior frontal gyrus		-22	8	68	3.99	
	L. Middle frontal gyrus	2567	-20	44	30	4.19	FDR 0.029
	L. Orbitofrontal gyrus		-28	42	-12	3.79	
Participant/judging videos < Control/judging videos	L. Lingual gyrus	22341	-18	-44	-10	7.48	FWE 0.000
	R. Fusiform gyrus		32	-78	-14	7.15	
	R. Superior temporal gyrus		54	-20	4	7.08	
	R. Inferior frontal gyrus (inferior operculum)	3041	40	6	32	6.90	FWE 0.032

Note. STAI = state anxiety levels. R. = right, L. = left, df = 1, 18

Table 2

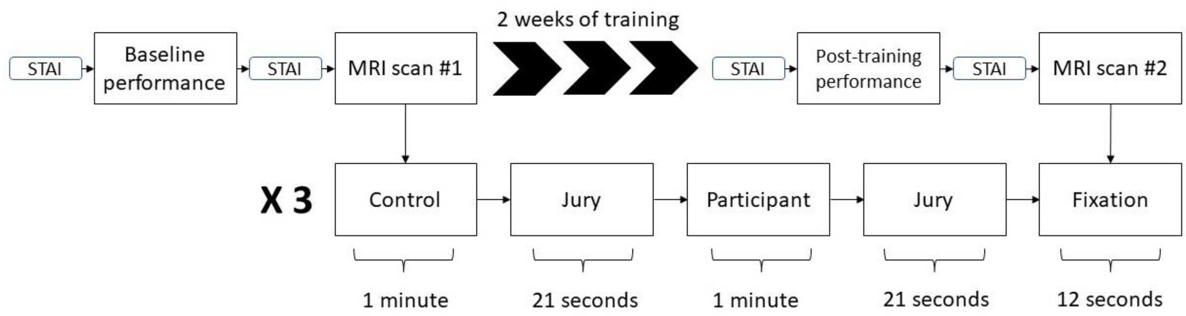
Greater Activity Post-Training than at Baseline in the Mindfulness and Control Groups

Region	Cluster size (voxels)	MNI Coordinates			*T*	FWE *p*-value
		X	Y	Z		
Mindfulness group						
R. Superior parietal gyrus	3754	16	-58	50	5.83	.003
R. Postcentral gyrus		22	-44	66	5.46	
L. Supramarginal gyrus	1969	-48	-48	34	8.45	.013
L. Inferior parietal lobule		-44	-42	38	6.42	
L. Dorsolateral prefrontal cortex	2666	-48	8	28	6.12	.013
L. Postcentral gyrus		-46	-14	42	5.00	
L. Thalamus	2480	-20	-14	0	7.29	.013
R. Substantia nigra		16	-20	-8	6.91	
L. Amygdala		-18	-4	-18	6.63	
Control group						
L. Heschel's gyrus	16731	-34	-30	-12	14.88	< .001
L. Cuneus		-12	-82	26	8.27	
R. Precentral gyrus	2926	52	-8	54	9.01	.01
R. Postcentral gyrus		56	-6	28	8.60	

Note. R. = right, L. = left, df = 1, 8. Controlled for STAI (state anxiety) scores.

Figure 1

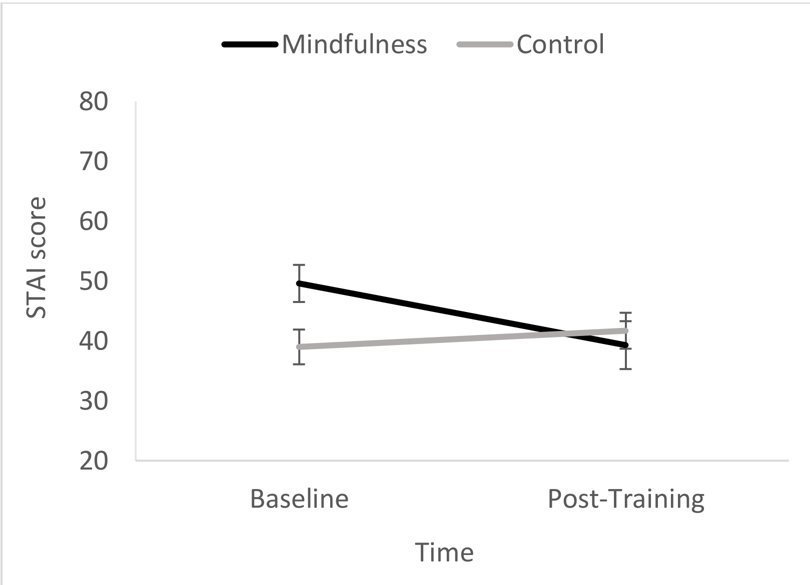
Flowchart of the Study's Procedure



Note. The topmost level demonstrates the overall study's procedure, and the second level demonstrates the anxiety-provoking task procedure performed during the MRI sessions. STAI = state anxiety levels recorded, X 3 = the sequence was repeated three times.

Figure 2

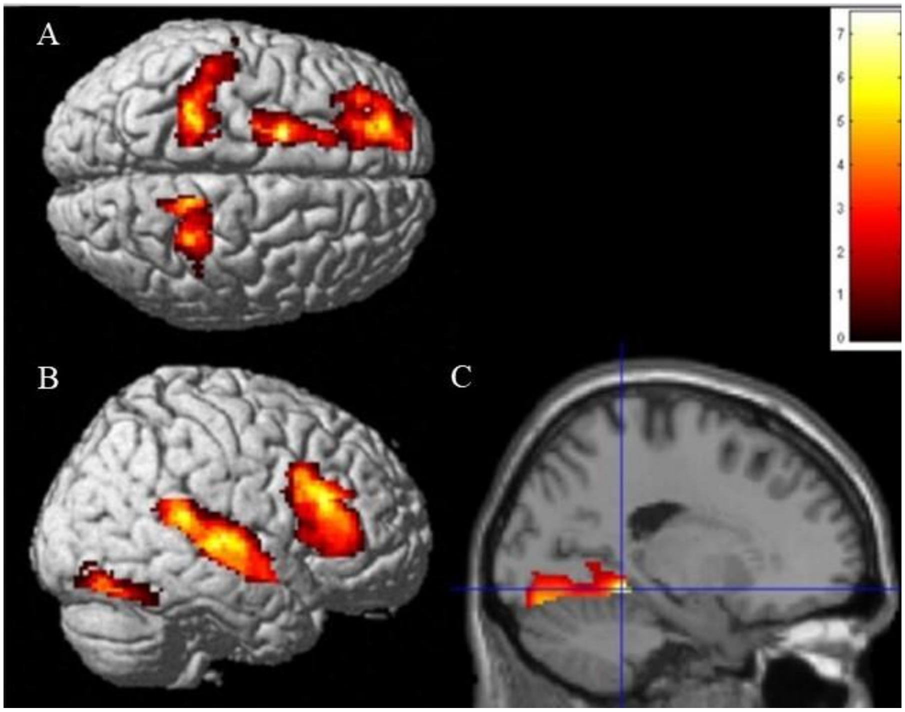
STAI Scores Across the Study in the Mindfulness and Control Groups



Note. STAI = state anxiety levels. Error bars denote the standard errors of the means.

Figure 3

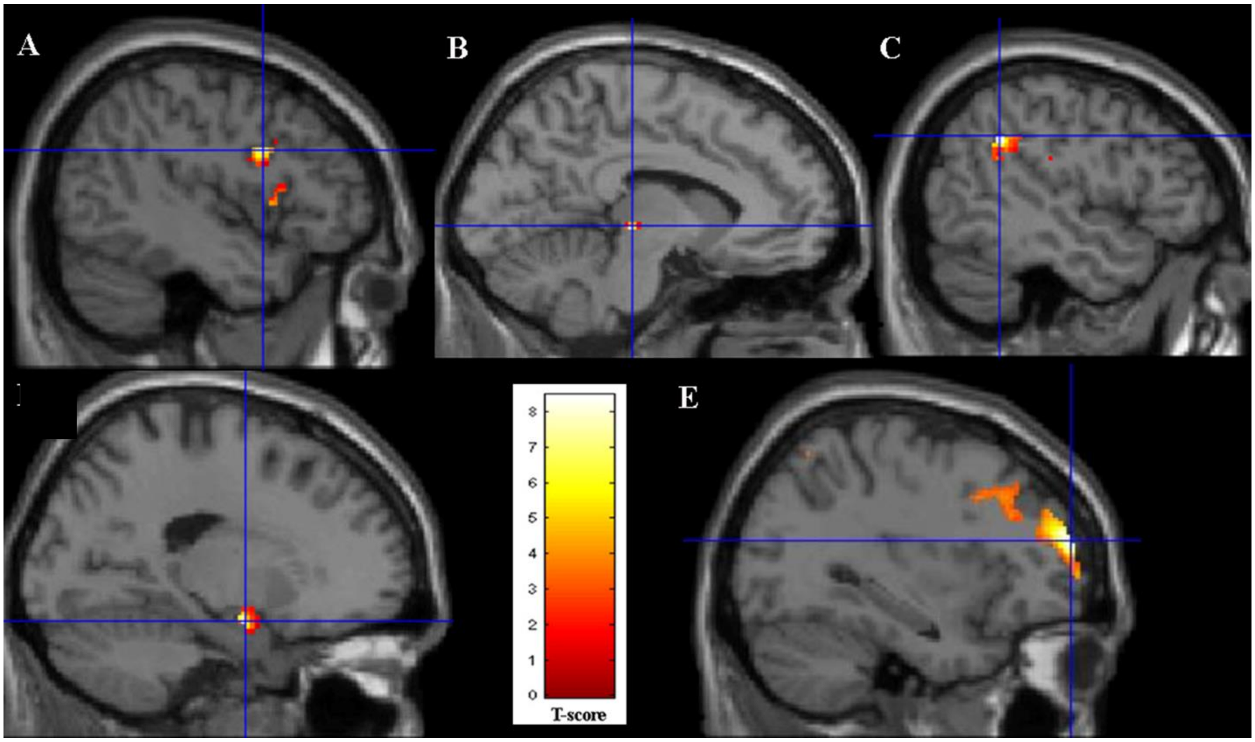
Neural Activity during the Anxiety-Provoking Task Validation with all 20 Participants



Note. A. represents more activity watching themselves play compared to watching the control play. B represents less activity when watching themselves play compared to watching the control play. C. is less activity in the left lingual gyrus when watching themselves play compared to watching the control play.

Figure 4

Neural Activity for the Group and Time Contrasts during the Anxiety-Provoking Task



Note. A-D represent the most significant increases in brain activity for the mindfulness group from baseline to post-training. A. Left DLPFC, B. Thalamus, C. Left Supramarginal gyrus, D. Left Amygdala. E. is the region of the left DLPFC where the mindfulness group showed significantly more activity than the control group post-training.

CHAPTER THREE: How does brief mindfulness training influence neurophysiological and performance indicators of working memory in musicians with music performance anxiety?

Abstract

Mindfulness demonstrates beneficial effects on working memory; however, its influence on working memory within musicians with music performance anxiety (MPA), for whom working memory is necessary for optimal performance, is untested. This exploratory study examined the association between brief mindfulness training and neurophysiological and behavioural activity during a letter n-back task, a common task to assess working memory. In this study, twenty musicians with MPA underwent fMRI while performing the n-back task (time 1). Ten musicians then participated in two weeks of mindfulness training, while ten did not. All participants completed the same scan sequence two weeks later (time 2). Results demonstrated that the control group had slower reaction times than the mindfulness group during the n-back task at time 2. Neurophysiological differences were also found between the mindfulness group and the control group at time 2. The mindfulness group had significantly less activity than controls in the left and right middle occipital gyri, the right and left lingual gyri, and in the right cuneus, suggesting improved attention regulation abilities following mindfulness training. The mindfulness group also showed a significant reduction in activity following the mindfulness training in the right middle frontal gyrus (DLPFC) and in the right supplementary motor area. No differences were observed in the control group from pre- to post-training. These results suggest more efficient working memory processes in the mindfulness group post-training. Although exploratory, this study provides results that warrant further investigation of mindfulness as a tool to help musicians with performance anxiety.

Introduction

Music performance anxiety (MPA) is the persistent and distressing anxiety related to performing and is experienced by 15-70% of musicians at various levels of study (Papageorgi, 2020). MPA may impair emotional (e.g., distressing thoughts), autonomic (e.g., tachycardia), behavioural (e.g., tremor), and cognitive (e.g., decreased motivation) processes (Kenny, 2005; Kenny, 2010), and these symptoms are especially present under conditions where musicians are evaluated (Rowland & van Lankveld, 2019). Medicinal interventions, such as the use of beta blockers to reduce physiological arousal symptoms of MPA, are common in musicians (31-34%; Kenny et al., 2014; Orejudo et al., 2018). However, these medications only address the physiological symptoms; they do not address musicians' cognitions or behaviours (Steenen et al., 2016). Cognitive Behavioural Therapy (CBT) and Acceptance Commitment Therapy (ACT) are other methods that musicians have used to combat MPA. Despite these methods to alleviate the symptoms of MPA, it has been noted that 19% of musicians consider abandoning music studies altogether due to MPA (Orejudo et al., 2018).

Music performance requires synchronization of a number of skills, including long-term, short-term and working memory, which are usually impaired by performance anxiety to some degree (Popean, 2019). One source of the anxiety is the worry about memory slips or memory blanks during a performance. This turns into a vicious cycle of anxiety, followed by memory lapses due to anxiety and so on. Working memory is "a cognitive system that actively holds information in the mind to facilitate cognitive operations" (Spencer, 2020, p. 545). Baddeley and Hitch's working memory model encompasses three components: the phonological loop, responsible for processing and storing auditory information; the visuospatial sketchpad, responsible for maintaining and manipulating visual and spatial information; and the central executive, which regulates these processes by maintaining goals and decision making in relation to the task, while utilizing attentional processes to accomplish successful working memory functions (Baddeley & Hitch, 1974). Baddeley also identified other functions of the central executive, including coordinating between multiple tasks (Baddeley et al. 1997), shifting between tasks (Baddeley, 1996), and selectively attending to and inhibiting stimuli (Baddeley et al., 1998). Concordantly, Miyake et al.'s (2000) model of executive control (i.e., shifting, updating, inhibiting) contributes to these working memory mechanisms. Through updating, which is especially important to working memory, individuals actively assess a stimulus' significance and eliminate old, irrelevant stimuli and replace them with newer, relevant stimuli. By shifting, individuals move their attention between tasks, operations, or mental sets (Monsell, 1996). Finally, through inhibition, dominant interfering information is deliberately suppressed. To summarize, when an incoming stimulus is detected, attentional processes are then used to hold the information in the mind and to manipulate that information toward goal-directed behaviour (Hartley & Hitch, 2022).

For musicians, working memory is essential for activities such as listening attentively to music and responding, visual aspects such as reading music notation, and motor skills (Pozenatto, 2020). Similarly, musicians may perform by memory (Iorio et al., 2022), which can be a source of stress and anxiety. Interestingly, musicians frequently outperform non-musicians on working memory tasks, including on the n-back task, a commonly used working memory task (Talamini et al., 2017). The n-back task is a popular working memory task that requires monitoring, updating, and manipulating information. In this task, participants are asked to respond whenever to a stimulus that is presented n stimuli before. For example, participants may be asked to respond to a stimulus 2-back (two stimuli before). In this case, participants would select the second A in the sequence A B A.

Although there is a vast amount of research on music performance and working memory, fewer studies have examined working memory in relation to performance anxiety, especially with musicians. This is important because, according to sports researchers, optimal performance involves strong working memory skills, as an individual must attend to task-relevant information, while ignoring non-task-relevant cues (Nideffer, 1992). Mindfulness, the practice of self-regulating the mind and body by engaging a specific attentional set (Cahn et al., 2006), may be an effective method to increase working memory functioning. Mindfulness, being aware and open in the present moment without judgement (Kabat-Zinn, 2003), has been used as a tool to alleviate the negative effects of performance anxiety (Hut et al., 2021; Lecuona et al., 2023; Stanson et al., 2022). For example, Lecuona et al. (2023) asked 151 musicians to self-report their mindfulness, MPA, and negative affect and found that dispositional mindfulness was negatively associated with negative affect and MPA. In addition, Stanson et al. (2022) examined the effects of a brief (two-week) mindfulness intervention on state anxiety (thought to represent MPA) before and after a performance pre- and post-intervention in twenty-six young adult musicians. They found that mindfulness was associated with reductions in anxiety. Another study (Czajkowski et al., 2022) interviewed twenty-five musicians after an 8-week MBSR/MBCT course to determine their experiences of mindfulness and its effect on MPA. Of the larger sample, 8 student musicians indicated reductions in pre-performance MPA symptoms (e.g., calmer breathing, less clammy hands, less heart pounding) after practicing mindfulness. In addition, in a qualitative study, 16 experts in meditation (e.g., musicians, performance coaches) found that meditation used in their practice had beneficial effects on musicians with MPA (Paese & Egermann, 2023).

Studies have demonstrated that mindfulness is also related to improved attentional functions (Sumantry & Steward, 2021). At any given time, our minds are presented with vast amounts of information, and attention is the cognitive ability to select and direct our awareness to certain stimuli (Morrison & Jha, 2015). According to Posner and Petersen (1990), attention can be divided into three subsystems: the alerting, orienting, and executive subsystems. The alerting subsystem is stimulus-driven and alerts us to incoming stimuli. The intentional, goal-driven systems include the orienting and executive subsystems, which direct our attention toward certain stimuli (orienting) and select which stimuli we attend to (executive). These attentional abilities are essential for working memory. Mindfulness is believed to alter working memory by inhibiting reactivity to non-goal-directed information, allowing for more task-relevant information to be attended to (Morrison & Jha, 2015).

Mindfulness may also influence working memory through increased emotional regulation by “altering the subjective meaning and/or perceived self-relevance of the present situation” (Gross, 2007, p. 33). Thus, mindfulness may allow the individual to appraise the stimulus as less threatening and as more challenging, increasing overall well-being. Researchers who study stress define stimuli as threatening or challenging (primary appraisal) according to whether the individual has the resources to cope with the demands (secondary appraisal; Lazarus & Folkman, 1984). More specifically, a stimulus is deemed *threatening* when it outweighs the individual’s ability and/or resources to cope, whereas a stimulus is deemed *challenging* when the individual perceives that they have adequate resources to cope with the demand. Studies have shown that threatening stimuli lead to poorer executive functioning, whereas challenging stimuli increase cognitive performance (Blascovich & Mendes, 2000; Blascovich & Tomaka, 1996; Kassam et al., 2009; Mendes et al., 2007). Indeed, ninety-seven university students participated in an experiment that examined challenge versus threat appraisals and working memory in response to task instructions (opportunity versus risk versus null). They found that appraising a task as threatening results in decreased positive affect and poorer performance on a working memory task (Chen & Qu, 2021). This is especially true for musicians as previous studies have demonstrated that musicians direct their attention to negative internal (e.g., fear of negative evaluation) and external (e.g., signs of boredom) signs of potential threat when performing (Goldin & Gross, 2010; Osborne & Franklin, 2002). Mindfulness may help musicians overcome this threat by influencing their ability to exert control over such negative rumination via increased attentional abilities (Ramel et al., 2004) and altering the subjective meaning of the stimuli, rendering the stimuli as challenging as opposed to threatening ("coping" in Lazarus and Folkman's transactional model of stress and coping; Lazarus & Folkman, 1984).

When examining the effects of mindfulness on attention and emotion regulation abilities, Tang et al. (2007) found significantly better working memory, specifically in the executive attention network, and self-regulation abilities in novice meditators after only five days of integrative body-mind training. When examining the influence of increased attentional and emotion regulation abilities specifically in relation to performance anxiety, a study by Röthlin et al. (2020) found that mindfulness training improved athletes' attentional control during training and performance and improved their ability to inhibit emotional interference during performance. Hut et al. (2021) also found that mindfulness training led to decreases in athletes' sports anxiety and increases in satisfaction with their attentional and emotion regulation abilities. These studies suggest that mindfulness is an effective tool to increase attentional and emotion regulation abilities, which may alleviate the detrimental effects of performance anxiety on working memory.

The neurophysiological effects of mindfulness on attention and emotion regulation have been explored by many researchers; however, the mechanism through which mindfulness influences performance anxiety remains unresolved. Results from studies by Nien et al. (2023) and Lutz et al. (2016) have hypothesized potential explanations for this relationship. Nien et al. (2023) found changes in neural activity in areas related to attention in athletes who were novice meditators. They used electroencephalography (EEG) to explore changes in neural activity while participants underwent three counterbalanced conditions: a mindfulness induction, a relaxation induction, and a control condition. During the mindfulness and relaxation inductions, compared to when in the control condition, participants had lower state anxiety levels, lower negative affect, and higher theta power in the frontal region of the brain, which has been linked to internally directed attention (Brandmeyer & Delorme, 2018) and has been found to be related to enhanced cognitive control and awareness (Cavanagh, et al., 2015; Tang et al., 2019). This suggests that brief mindfulness-related activities in novice meditators recruit frontal brain regions in order to maintain attentional control. In contrast, practicing mindfulness for a longer period of time leads to decreased activity in frontal regions (e.g., cortical midline structures, dorsolateral prefrontal cortex; Chai et al., 2018). For example, Lutz et al. (2016) found significant deactivations in cortical midline structures, including prefrontal and occipital midline regions covering parts of the precuneus/posterior cingulate cortex and the cuneus, after undergoing short periods of mindful self-awareness in novice and experienced meditators. However, the deactivations were more pronounced in the experienced meditators. Perhaps enhanced attentional and emotion regulation abilities gained through mindfulness practice leads to increased working memory performance by requiring less cognitive effort from these brain regions over time (Lutz et al., 2008; Stein et al., 2022). Thus, mindfulness may help musicians with performance anxiety by increasing their working memory ability, allowing them to achieve their optimal performance.

The current study aimed to address the relatively unexplored relationship between mindfulness, working memory, and performance anxiety in musicians. A two-week mindfulness training program was employed, along with functional magnetic resonance imaging (fMRI) during a letter n-back task, to investigate any between- (mindfulness and control) and within-group differences in performance and neural activity.

Methodology

Participants

Twenty musicians with self-identified MPA were recruited for this study. Participants were recruited until no other participants agreed to participate. Ten participants identified as female, and ten identified as male. The mean age of participants was 23.4 (*SD* = 2.9), and the participants played a range of instruments (e.g., violin, percussion, cello). Participants were recruited through convenience sampling via email, through posters at a Canadian university's music building, and by contacting private instructors. These twenty participants were recruited from a larger study (Stanson et al., 2023), which demonstrated that participants had decreased state anxiety prior to a musical performance after undergoing two weeks of mindfulness training. The focus of the current study was the neurophysiological impact of the mindfulness training on a subset of these participants that met criteria for fMRI. This study was approved by a Canadian university's research ethics board.

Participants were included in the study if they had achieved Grade 7 from the Royal Conservatory of Music or if they had completed or were currently completing an undergraduate or graduate degree program in music. These inclusion criteria were chosen because those levels are generally thought of as “late intermediate/early advanced.” This would suggest that musicians at this level perform regularly, especially in evaluative circumstances, which requires advanced working memory skills. In the current study, most participants had a Bachelor of Music, and the median years of playing their instrument was 10 years. Participants were also included if they had normal or corrected vision and had normal hearing. Participants were excluded if they had non-removable metal in their body or implanted devices, if they were taking medication for any psychological disorders, 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 back problems, if they were currently pregnant or breastfeeding, or if they were claustrophobic. Participants were also excluded if they were currently engaging in mindfulness training or if they engaged in any kind of mindfulness training in the past.

Measures

Demographic and Health Questionnaire

Demographic and health information, such as participants’ age, sex, type of instrument played, experience with mindfulness activities (e.g., MBSR, meditation, yoga), and whether they had pre-existing psychological conditions, was collected prior to experimentation.

Procedure

The first ten participants who registered for the study were allocated to the experimental (mindfulness) condition, and the next ten participants were allocated to the control condition. All participants participated in an fMRI and underwent a letter n-back task Participants participated in a one-hour MRI scan within 6 days of their performance. This paper describes only the fMRI results from a working memory letter n-back task (described below). The experimental group then underwent two weeks of mindfulness training, while the control group refrained from any mindfulness activities. All participants took part in post-training data collection identical to the pre-training session. Within 2 days of the post-training performance, the participants underwent the same imaging sequences as the first scanning session. All data collection activities occurred within a period of 4 months.

Mindfulness Training

A two-week mindfulness training program, influenced by previous studies examining the effects of mindfulness on MPA (Czajkowski et al., 2022; Lecuona et al., 2023; Stanson et al., 2022), was employed. In this study, a condensed version of the traditional 8-week mindfulness based-stress reduction (MBSR) program was used within the experimental condition. The sessions were taught by a registered Mindfulness-Based Cognitive Therapy facilitator. The two-week training program comprised ten one-hour sessions over the course of two weeks. Participants were required to attend a minimum of six sessions. Each session consisted of a variety of breath awareness, body scanning, mindful walking, meditation, and qigong and was conducted in a group format. Participants were also encouraged to talk in discussion groups about their experiences with MPA, their experiences with mindfulness so far, and their daily stressors. Participants were asked not to participate in any additional mindfulness activities throughout the mindfulness training program.

fMRI procedure

Participants underwent the 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-

channel head coil. Participants' brain activity was measured during the n-back task, a common method to measure individuals' working memory. The block design task included the presentation of black letters one at a time on a white screen for 500 milliseconds with an inter-stimulus interval of 1500 milliseconds. The task included two conditions of instructions: a control or baseline condition ('Press for X'; a button press required for every X presented) and a working memory condition ('Press for 2-back'; a button press required when the letter presented was the same as the one presented 2 letters prior; no Xs were presented in these blocks). For example, if they saw A then B then A, they would push the button on the second A. Six blocks of each condition were undertaken with 16 stimuli presented randomly in each block. Six responses were required within each block. Rest periods were interspersed between blocks for 21 seconds with the word 'Rest' on the screen. 21-second rests were used to allow the hemodynamic response to return to baseline before starting the next block of responses. Whole brain echo planar fMRI was performed using a gradient echo pulse sequence (TR/TE 3000/34 ms, FA 90°, FOV 200 × 200 mm2, voxel size 1.6 mm × 1.6 mm × 3 mm, 48 axial slices, slice thickness 3 mm, band-width 2894 Hz).

Data Analysis

The fMRI data were post-processed and analyzed using Statistical Parametric Mapping 12 (SPM12). The fMRI scans were motion-corrected through realignment, normalized to the standard SPM Montreal Neurological Institute template, and spatially smoothed with a 6 mm FWHM Gaussian kernel. Individual participant analyses were performed with the functional images from the task. The contrast of interest, highlighting working memory, was the 'Press for 2-back' minus 'Press for X' contrast. Motion correction was applied as a regressor for all first-level analyses. Second-level analyses were performed between and within groups. Baseline fMRI scans (time 1) were compared to post-mindfulness scans (time 2) with paired t-tests conducted for each group of participants. Groups were compared at both time 1 and time 2 with an ANOVA and followed by post-hoc simple t-tests. All analyses were whole-brain investigations and were conducted at a set threshold of puncorr = 0.001, with a cluster-wise correction at pFWE = 0.001 and a set cluster size larger than 10 voxels.

Performance outcomes, reaction time and errors, were analysed with a 2 x 2 ANOVA. Post-hoc simple t-tests were then performed to identify where the significant effects were present.

Results

Behavioural and Sociodemographic

There were no significant group differences in sex (5 females and 5 males in each group), age, whether participants had pre-existing psychological conditions, experience with mindfulness activities, age since starting music, number of years of music lessons, and number of hours of practice in adolescence or as a young adult. However, there were differences in the number of hours of practice currently, with the mindfulness group practicing more than the control group, $t(17) = 2.30$, $p = .034$.

Accuracy and Reaction Times

When examining the reaction times of both the mindfulness and control groups between the 0-back and the 2-back at time 1, there was a significant effect of task, such that reaction times for the 2-back were longer than reaction times for the 0-back ($F(1,36) = 18.30$, $p < .001$, $\eta_p^2 = .337$), but no significant effect of group or group x task interaction was observed. When examining the reaction times of both the mindfulness and control groups between the 0-back and 2-back at time 2, there was a significant group effect ($F(1,36) = 22.16$, $p < .001$, $\eta_p^2 = .381$) and a significant effect of task ($F(1,36) = 22.71$, $p < .001$, $\eta_p^2 = .387$), but no interaction. Specifically, the controls had slower reaction times than the mindfulness group, and the reaction times for the 2-back were slower than the reaction times for the 0-back.

Reaction times at time 1 and time 2 were examined for both the 0-back and the 2-back for both the mindfulness and control groups. For the 0-back, there was a significant group x time interaction, such that the control group's reaction times increased over time and there was a difference between the control group's reaction times and those of the mindfulness group at time 2 ($F(1,18) = 9.14$, $p = .007$, $\eta_p^2 = .337$). When examining the 2-back condition, there was a significant interaction ($F(1,18) = 6.48$, $p = .020$, $\eta_p^2 = .265$). Specifically, at time 2, the control group's reaction times were slower than those of the mindfulness group. See Table 1 for the mean reaction times for the 0-back and 2-back for the mindfulness and control groups at time 1 and time 2 and Table 2 for a summary of reaction time differences between the mindfulness and control groups from time 1 to time 2.

Commission (i.e., when a participant responds to a stimulus when they should not) and omission (i.e., when a participant does not respond to a stimulus when they should have) errors at time 1 and time 2 for the 0-back and 2-back for both groups were also examined. There were no significant effects of group or time and there was no significant group x time interaction for either type of error. See Table 3 for the means and standard errors of the commission and omission errors for the 0-back and 2-back for the mindfulness and control groups at time 1 and time 2.

n-back fMRI task

Neural activity was significantly different in the mindfulness group after the 2-week training program. More specifically, there was significantly less activity after the mindfulness training compared to time 1 in the right middle frontal gyrus and the right supplementary motor area (see Table 4 and Figure 1). There were no significant differences in the control group.

No significant differences were observed between the mindfulness and control groups when examining neural activity at time 1. There were, however, significant differences for the time 2 group comparisons. The significant differences were localized in posterior brain regions with the mindfulness group having significantly less activity than controls in bilateral middle occipital gyri, bilateral lingual gyri, and in the right cuneus (See Table 4 and Figure 2).

Discussion

This exploratory study examined the association between brief mindfulness training and neurophysiological activity during a working memory task in musicians with MPA. Results showed that the mindfulness group had significantly less activity in several visual areas (e.g., lingual gyrus) compared to the controls at time 2. As the lingual gyrus is involved in pain perception, mindfulness may have allowed musicians to reinterpret the working memory task as painful/threatening to challenging, allowing musicians to focus their attentional resources on the cognitive task at hand. The most robust finding was a significant reduction in brain activity in the right middle frontal gyrus and the right supplementary motor area from time 1 to time 2 in the mindfulness group. Decreased neural activity in the DLPFC and supplementary motor area (SMA) may imply that when the musicians engaged in the working memory task, fewer frontal resources were used (Lutz et al., 2014). In addition, the mindfulness group had significantly quicker reaction times than the controls at time 2 during the n-back task, with no concomitant increase in errors. These neurophysiological and performance related results are suggestive of improved attention during the task; however, previous studies have demonstrated decreased omission errors, representing increased sustained attention, in those who undergo mindfulness training when compared to a control group (Ueberholz & Fiocco, 2022).

Mindfulness is defined as being presently aware without judgment. This is counter to the rumination (Nolen-Hoeksema et al., 2008) and fear of negative evaluation (Hur et al., 2021) that is often experienced by individuals with MPA (Nielsen et al., 2018; Osborne & Franklin, 2002). Indeed, it has been suggested that down-regulation of self-referential brain regions is associated with mindful self-awareness (Lutz et al., 2016). Lutz et al. (2016) found significantly decreased activation in mindfulness-naïve participants and long-term meditators in cortical midline structures, including prefrontal regions, the anterior cingulum, and occipital midline regions covering parts of the precuneus/PCC and cuneus, after undergoing a mindful self-awareness paradigm in comparison to a self-referential paradigm. Consistent with these results, the present study exhibited decreased activation of the cuneus in the mindfulness group compared to controls. Activity in the cuneus is linked to internally directed attention (Benedek et al., 2016). Individuals with anxiety, such as those with social anxiety disorder, have been shown to allocate their attentional resources to self-referential and self-evaluative processes (Hur et al., 2021). Decreased activation in the cuneus may therefore be associated with greater mindful awareness and the allocation of fewer attentional resources to self-referential processes, which is beneficial for musicians as they have been shown to engage in negative self-talk (Rowland & van Lankveld, 2019).

In addition, the mindfulness group also demonstrated decreased neural activity in the middle occipital gyrus and the lingual gyrus. The lingual gyrus and the cuneus are necessary for higher order visual processing, playing an important role in visual attention (Beason-Held et al., 1998; Palejwala et al., 2021), which is necessary for tasks such a reading notation (Pozenatto,

2020) The lingual gyrus has also been associated with the perception of pain, suggesting its role in the control of emotions associated with painful stimuli (Palejwala et al., 2021). Mindfulness may help musicians through increased attentional ability and by altering the subjective meaning of the stimulus (i.e., working memory task) from painful/threatening to challenging, allowing musicians to direct their attentional and emotional resources towards the cognitive task at hand. This is supported in the current study by the performance data, in which the mindfulness group had faster reaction times than the control group.

Further evidence of an effect of mindfulness on neural activity during working memory is provided by the significant neurophysiological changes in the mindfulness group from time 1 to time 2, with no significant changes in neural activity in the control group. Specifically, the mindfulness group exhibited decreased brain activity in the right middle frontal gyrus (DLPFC) and in the right SMA. The DLPFC is involved in monitoring (i.e., actively retaining) and manipulating (i.e., updating or selecting) items in working memory, especially regarding visuospatial information (Barbey et al., 2013). When the DLPFC is engaged in these working memory operations, most studies find increased activation in this area (Barbey et al., 2013; Owen et al., 2005; Wager & Smith, 2003). Increased DLFPC activity is also related to cognitive self-reflection (as opposed to emotion-introspection; Herwig et al., 2010). This study found decreased DLPFC activity after mindfulness training, which may imply that mindfulness training allows individuals to allocate fewer frontal resources when engaging in working memory processes, reflecting an efficient use of this brain region (Lutz et al., 2014), as well as a change in cognition from self-reflection towards mindful awareness. This is supported by the performance data, in which the control group’s reaction times were slower than those of the mindfulness group, perhaps demonstrating more efficient working memory processes in the mindfulness group.

The supplementary motor area (SMA) has been shown to be part of a widespread fronto-parietal network underlying working memory (Owen et al., 2005; Rottschy et al., 2012). The SMA is a "secondary motor" region, representing the intersection of motor and cognitive functions (Marvel et al., 2020). Secondary motor regions are activated prior to overt motor execution and may support working memory by creating motor traces, which are "imagined motor representations of salient external or internal information in the absence of overt [movement]" (Leisman et al., 2016 as cited in Marvel et al., 2020, p. 8). Motor traces can be used in the maintenance of content by holding the stimulus (e.g., a letter) in mind without saying it aloud. Lesion studies of the SMA have also demonstrated working memory impairments, specifically in information manipulation: Patients with SMA lesions were able to temporarily sustain information, but could not mentally manipulate it (Cañas et al., 2018). During the n-back task, activation changes reflect the maintenance, monitoring, and manipulation processes of working memory (Jablonska et al., 2020). The present study found decreased activation of the SMA after mindfulness training, which may underscore less reliance on motor traces, and thus fewer attentional resources required, during the working memory task (Marvel et al., 2020). It may also signify a shift from future-oriented thinking and anticipation of potential threat to more present awareness. This may be very beneficial for musicians as they experience MPA (Miloyan et al., 2016).

Findings from this study suggest that mindfulness may be a useful tool to improve higher-order cognitive processes, such as working memory. Both the neurophysiological and performance results suggest the benefits of mindfulness, potentially through its effects on attention and emotion regulation. Working memory is an important ability for musicians and intertwines through multiple aspects of musical performance. Fear of memory blanks or lapses is a source of anxiety for many musicians, so if mindfulness can help enhance working memory, this may in turn build confidence in musicians to counter MPA. The vicious cycle of worry about forgetting notes that so often elicits MPA, which then leads to memory lapses and so on, may be stopped, and optimal performances that are much more enjoyable to play, may be achieved.

Strengths, Limitations, and Future Directions

The most significant limitation of this study is sample size. Although this study was exploratory, future studies should recruit larger samples to further explore the relationship between mindfulness and neurophysiological activity during a working memory task in musicians with performance anxiety. Another limitation is that this study did not randomly assign participants to each condition. The first ten musicians were allocated to the mindfulness condition, and the next ten musicians were allocated to the control condition. Perhaps participants allocated to the mindfulness group had better attentional processes before the start of the study, which may indicate that they are more successful at inhibiting reactivity to non-goal-directed information, in which case they were better able to hold and manipulate information – processes necessary for effective working memory. As a result, participants in the mindfulness group may have had better working memory capacity initially, which may affect the efficacy of the mindfulness training. Ideally, future studies should employ a crossover experimental design, in which all musicians undergo the same mindfulness training. Future studies should also have an active control group, so that group cohesion and group activity can be controlled for. This was not possible in the current study. Another possible limitation is that this study used fMRI exclusively, instead of combined with electroencephalography (EEG). fMRI has better spatial resolution with lower temporal resolution, whereas EEG has better temporal resolution with lower spatial resolution. This is important to consider as EEG may measure more accurate reaction times, and fMRI may better identify the brain areas specifically activated during working memory performance. Complementary neuroimaging modalities are recommended as there is strong evidence of coupling of neural activity between fMRI and EEG (Ahmad et al., 2016). Altogether, results from this study should be interpreted with caution. Although there were several limitations, there were also strengths. First, the study used a longitudinal design, which demonstrated the relationship between mindfulness training and neurophysiology during a working memory task. This is a strength because most studies examining the neurophysiological mechanisms of mindfulness use cross-sectional designs (Malinowski, 2013; Tang et al., 2015). Another strength is the brevity of the mindfulness training program, allowing musicians with MPA to access a short and effective tool to combat symptoms of MPA. Significant neural and performance effects were observed after only two weeks of mindfulness training. Future studies could also employ a follow-up session to determine whether these effects are enduring over time.

Conclusion

Music performance involves a number of skills involving working memory, which are usually impaired by MPA (Popean, 2019), The findings from this exploratory study suggest that mindfulness training influences neurophysiology that may be beneficial for musicians' working memory and consequently, MPA. This is indicated by their reaction times and changes in neural activity in brain regions implicated in attention and emotion regulation, which are necessary for effective working memory, and thus music performance. Therefore, results from this study suggest that mindfulness may be a tool to help musicians achieve their optimal performance.

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Table 1

Mean reaction times, in milliseconds, for the 0-back and 2-back conditions for the mindfulness and control groups at time 1 and time 2

	Mindfulness		**Control**	
	M	***SD***	***M***	***SD***
Time 1				
0-back	477.3	55.4	485.3	54.6
2-back	588.5	116.6	619.3	115.0
Time 2				
0-back	473.2	56.6	534.7	36.9
2-back	535.9	92.5	675.5	71.6

Table 2

Differences in reaction times of the mindfulness and control groups between the 0-back and the 2-back at time 1 and time 2

	Main effect of task	**Main effect of group**	**Task x group interaction**
Time 1 2-back – 0-back	$p < .001$ 2-back>0-back	n.s.	n.s.
Time 2 2-back – 0-back	$p < .001$ 2-back>0-back	$p < .001$ Control>Mindfulness	n.s.
Time 1 to 2 0-back	n.p.	n.p.	$p = .007$ Control time 1>Control time 2 Control>Mindfulness at time 2
Time 1 to 2 2-back	n.p.	n.p.	$p = .020$ Control>Mindfulness at time 2

Note. n.p. = not presented due to a significant interaction, n.s. = not significant

Table 3

Means and standard deviations of commission and omission errors during the 0-back and 2-back for the mindfulness and control groups at time 1 and time 2

	Mindfulness		Control	
	M	***SD***	***M***	***SD***
Time 1				
Commission errors 0-back	0.1	0.3	0.3	0.5
Omission errors 0-back	0.1	0.3	0	0
Commission errors 2-back	1	1.3	1.5	1.2
Omission errors 2-back	0.9	1.2	2.0	4.4
Time 2				
Commission errors 0-back	0.1	0.3	0.3	0.5
Omission errors 0-back	0.3	0.7	0.1	0.3
Commission errors 2-back	0.4	1.3	1.1	1.9
Omission errors 2-back	0.7	1.3	2.0	3.2

Table 4

Between- and within-group differences in neural activity during the n-back working memory task for the 2-back – press for X contrast

Comparison	Region	Cluster size (voxels)	MNI Coordinates			*T*	*p*-value (FWE)
			X	Y	Z		
Mindfulness Time 2[a] < 1	R. Middle frontal gyrus (DLPFC)	207	32	50	14	9.85	.001
	R. Supplementary motor area	116	10	18	60	7.84	.027
Time 2 Mindfulness < Controls[b]	L. Middle occipital gyrus	4556	-18	-86	14	5.13	.002
	R. Middle occipital gyrus		36	-78	28	3.88	
	R. Lingual gyrus		18	-70	2	4.47	
	L. Lingual gyrus		-20	-70	-2	3.97	
	R. Cuneus		8	-90	18	4.33	

Note. R. = right, L. = left, [a] *df* = 18, [b] *df* = 1, 18,

Figure 1

Significantly less activity in the A-right dorsolateral prefrontal cortex and B-supplementary motor area in the mindfulness group post-training compared to pre-training

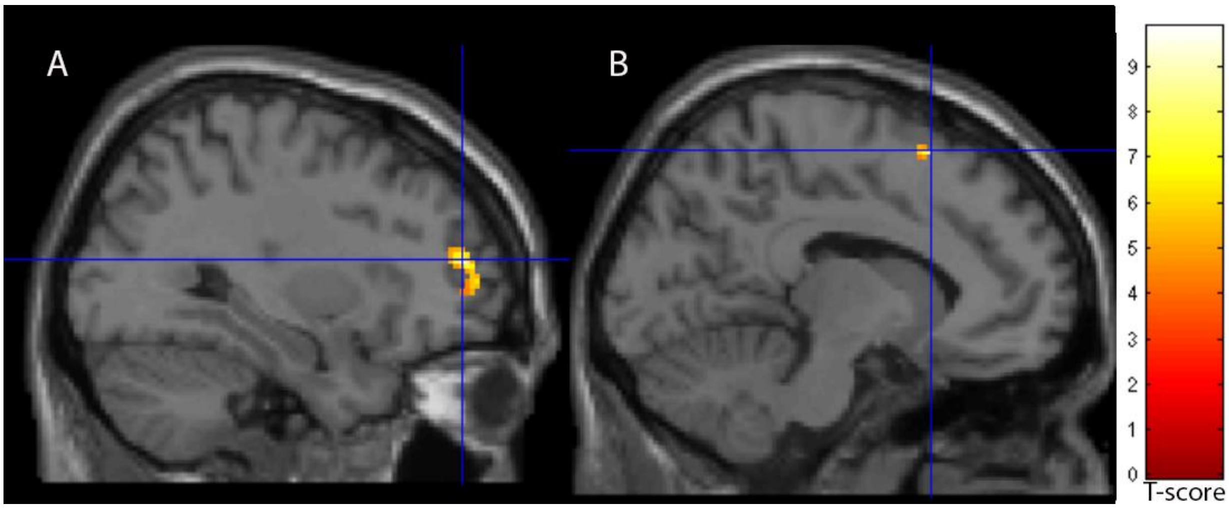
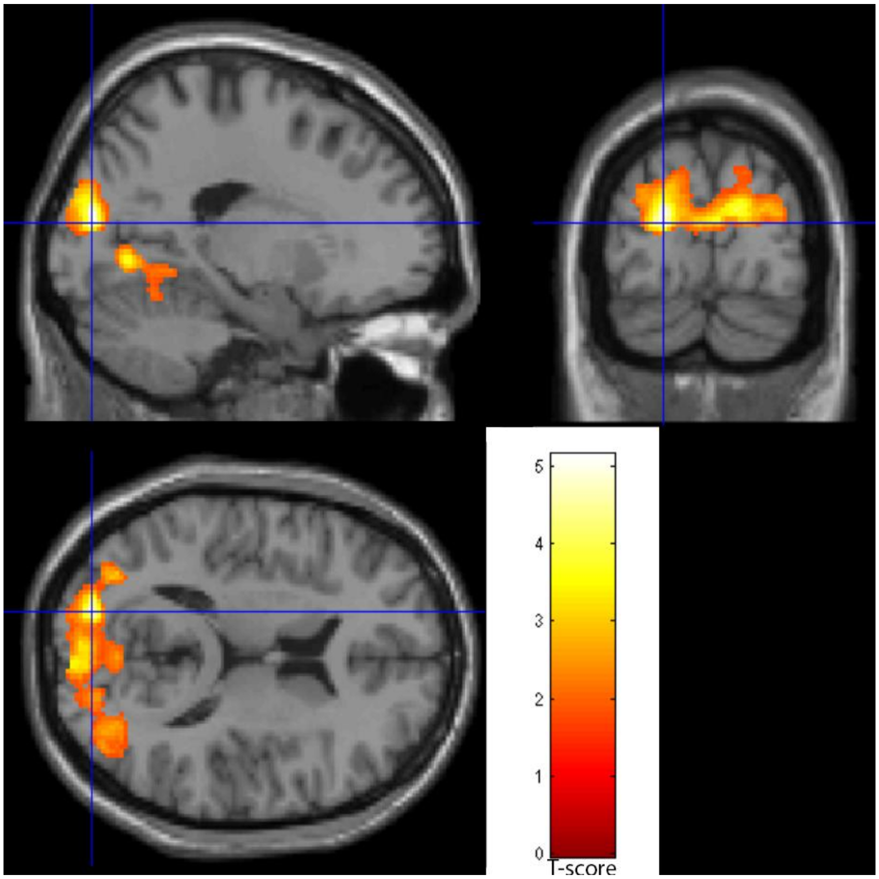


Figure 2

Significantly less activity in the visual cortex bilaterally in the mindfulness group compared to the control group at time 2



CHAPTER FOUR: Examining how brief mindfulness training influences communication within the brain of musicians with music performance anxiety: A resting state fMRI study

Abstract

Many musicians endure music performance anxiety (MPA), which may affect their psychological and physiological functioning. Mindfulness, being aware in the present moment without judgment, has been found to help ease anxiety. Mindfulness may also help alleviate the negative effects of MPA, but what is the neurophysiological basis for this effect? Core components of mindfulness, including emotional processing and acceptance, are related to specific patterns of brain activity. In the current study, twenty musicians with MPA underwent a resting state functional MRI scan (time 1), a method to examine the communication between brain regions at rest. Ten musicians then underwent two weeks of mindfulness training, while ten did not. The same scan sequence was repeated in all participants two weeks later (time 2). Compared to time 1, participants in the mindfulness group exhibited decreased resting state functional connectivity between areas of the prefrontal cortex and the vermis 6 and crus II at time 2. These two areas of the cerebellum are related to emotional processing and acceptance. Changes in communication between these brain regions and the prefrontal cortex suggest the neurophysiological influences of mindfulness and how mindfulness can be used to strengthen emotion regulation networks in musicians with MPA.

Introduction

Mindfulness is "paying attention in a particular way: on purpose, in the present moment, and nonjudgmentally" (Kabat-Zinn, 1994, p. 4). It comprises two components. The first component is self-regulation of attention, which refers to one's awareness of the present moment and one's ability to shift one's attention from one aspect of the experience to another (Bishop et al., 2004). The second component is being open and accepting of the current experience, which refers to experiencing the moment nonjudgmentally, without preoccupation or suppression of the experience (Bishop et al., 2004; Keng et al., 2011). Mindfulness has been used by Buddhists and other spiritual groups for centuries and has been used in Western contexts mostly since the 1970s (Kabat-Zinn, 1982; Keng et al., 2011). It has been used for a wide range of applications, including to reduce stress, anxiety, and depression in healthy individuals and various clinical groups, and it demonstrates moderate to high effectiveness in these applications (Khoury et al., 2015; Zhang et al., 2021). The study of mindfulness to reduce music performance anxiety (MPA) – "the experience of marked and persistent anxious apprehension related to musical performance…" (Kenny, 2010, p. 433) – has been of particular interest in recent years, with some studies demonstrating that increased mindfulness is associated with decreased MPA (Czajkowski et al., 2020; Diaz et al., 2018; Moral-Bofill et al., 2022; Rodríguez-Carvajal et al., 2017).

MPA is a significant problem for musicians as it is pervasive and can be psychologically and physiologically demanding (Fernholz et al., 2019; Guyon et al., 2020). MPA may affect the quality of performance and may lead to psychological distress (Osborne & Kirsner, 2022). To cope with MPA, many musicians turn to medications, recreational drugs, and alcohol (Kenny et al., 2014), and musicians are three times more likely than the general population to undergo psychotherapy (Vaag et al., 2016). As previously mentioned, studies have examined mindfulness' efficacy as a coping tool for MPA; however, few studies have examined the neurophysiological effects of mindfulness in relation to MPA.

Resting state functional magnetic resonance imaging is a brain imaging technique that provides valuable information on how regions of the brain communicate with each other when no task is required. This type of imaging provides evidence of neural networks working together for specific outcomes, referred to as functional connectivity. Some networks have been shown to alter with mindfulness interventions (Rahrig et al., 2022), most notably the default mode network (DMN), the frontoparietal network (CEN), and the salience network (SN). The DMN includes the medial prefrontal cortex (PFC), the posterior cingulate cortex (PCC), the posterior/lateral parietal cortices, and the parahippocampal gyrus (Buckner, 2008; Malinowski, 2013) and is involved in mind wandering (Hasenkamp et al., 2012). Meanwhile, the salience network consists of the anterior cingulate cortex (ACC), the anterior insula, and the anterior PFC and is involved in detecting relevant and salient stimuli (Hasenkamp et al., 2012). Finally, the CEN consists of the PFC and the posterior parietal cortex and is involved in attentional disengagement and in re-orienting or directing attention while maintaining a goal (Hasenkamp et al., 2012). These three networks work together during mindful attentional awareness. The DMN is activated when the mind wanders, the SN recognizes the mind wandering, and the CEN lets go of the distracting thought through attentional disengagement (Malinowski, 2013).

Previous studies have demonstrated the effect mindfulness has on the functional connectivity of these networks. A recent meta-analysis found significantly greater resting state functional connectivity (rsFC) between the left middle cingulate (SN) and the PCC (DMN) among twelve studies employing mindfulness-based training interventions (Rahrig et al., 2022).

Among the studies included in the meta-analysis, one found stronger coupling in experienced meditators between the PCC (DMN), dorsal ACC (SN), and dorsolateral PFC (CEN), at baseline and during meditation (Brewer et al., 2011), while another study found increased rsFC between regions of the DMN and SN (Kwak et al., 2019). They conducted a four-day meditation intervention with a meditation group and a relaxation (control) group and found increased rsFC between the left rostral ACC (SN) and the dorsomedial PFC, precuneus, and angular gyrus (all DMN regions) immediately post-intervention in the meditation group compared with the relaxation group. They also found increased rsFC between the right caudate, ACC (SN) and the PCC (DMN) in the meditation group post-intervention. Finally, a recent study by Bremer et al. (2022) found increased rsFC between DMN and SN regions and between SN and CEN regions in healthy participants after one month of mindful meditation training.

Although MPA is often referred to as a social anxiety disorder, a recent study by Wiedemann et al. (2022) found that generalized anxiety disorder is actually the best predictor of MPA among all major *DSM-5* anxiety types. When examining the effects of mindfulness on rsFC in individuals with generalized anxiety disorder, distinct patterns emerge (Zhao et al., 2019). Mainly, increased rsFC between the PCC (DMN) and the ACC (SN) and insula (SN) was observed. Another study by Kennedy et al. (2022) examined the effects of a ten-week mindfulness intervention on subjective anxiety and attention in children with subclinical anxiety-related attention impairments. They found increased rsFC of regions in the SN (i.e., ACC and insula) with regions in the DMN (i.e., supramarginal gyrus, ventromedial PFC, PCC, amygdala, and hippocampus) and regions in the CEN (i.e., dorsolateral PFC and inferior frontal gyrus). They also found increased rsFC between regions of the CEN and the caudate pre-intervention, which was associated with subjective anxiety, suggesting that this coupling is related to increased anxiety. Post-intervention, however, they did not find this relationship, suggesting regulation of participants' rsFC with decreased subjective anxiety scores.

As demonstrated, many studies have examined the relationship between mindfulness and rsFC, and some have even examined this relationship in individuals with GAD; however, the current study examined rsFC of musicians with MPA before and after a brief mindfulness training program. Taken together, results from previous studies demonstrate that mindfulness affects rsFC in areas of the DMN, SN, and CEN and that these results are associated with decreases in subjective anxiety. Therefore, it was hypothesized that the mindfulness group would demonstrate increased rsFC in regions of the DMN, SN, and CEN, whereas participants in the control condition would show no changes.

Methodology

Participants

Twenty participants with self-identified MPA were recruited for this study. Participants were between the ages of 18 and 28 (M = 23.4, SD = 2.9) and played a range of instruments. Ten participants identified as female, and ten identified as male. Participants were recruited through posters at a Canadian university's music building, through convenience sampling via email, and by contacting private instructors to ask for participation. The first ten participants who registered for the study were allocated to the experimental (mindfulness) condition, and the next ten were allocated to the control condition. This study was approved by the Canadian university's research ethics board. These twenty participants were recruited from a larger study (Stanson et al., 2022), which demonstrated that participants in the mindfulness group decreased in self-reported anxiety from time 1 to time 2, while participants in the control group showed no change. However, this was not the focus of the current study.

Participants were included in the study if they had achieved Grade 7 from the Royal Conservatory of Music or if they had completed or were currently completing an undergraduate or graduate degree program in music. Participants were also included if they had normal or corrected vision and had normal hearing. Participants were excluded if they engaged in any kind of mindfulness training currently or in the past. Participants were also excluded if they were taking medication for any psychological disorders, 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, if they were currently pregnant or breastfeeding, if they had back problems, or if they were claustrophobic.

Measures

Demographic and Health Questionnaire

Prior to experimentation, demographic and health information was collected, including participants' sex, age, experience with mindfulness activities (e.g., MBSR, yoga, meditation), type of instrument, and whether they had pre-existing psychological conditions.

Procedure

The first step for each participant was to perform a solo repertoire in front of a panel of two judges. Each participant's performance was video-recorded, which was used for an anxiety-provoking task during the fMRI session (more information about this task can be found in Boileau et al., in review). Within 6 days (M = 6.7, SD = 2.3) of their performance, participants underwent a one-hour MRI scan, which included, in order, a high-resolution structural scan, a resting state fMRI scan (described below), a working memory n-back task, an anxiety-provoking task and a diffusion tensor imaging sequence. The experimental group then underwent two weeks of mindfulness training. The control group did not practice any mindfulness activities throughout the duration of the study. At the end of the two-week training period, all participants took part in post-training data collection, which had an identical protocol to the pre-training session. Within 2 days (M = 2.2, SD = 2.9) of the post-training performance session, participants underwent another one-hour MRI session, which included the same imaging sequences as the first scanning session.

Mindfulness Training

Participants in the experimental condition underwent a two-week mindfulness training program, which was a condensed version of the traditional eight-week mindfulness-based stress reduction (MBSR) training program. The mindfulness training program comprised ten one-hour sessions over the course of two weeks, and participants were required to attend a minimum of six sessions. Each session was conducted in a group format and consisted of a variety of meditation, breath awareness, body scanning, mindful walking, and qigong. Each session also consisted of discussion groups, in which participants were encouraged to talk about their experience with MPA in the past, their experiences with mindfulness training so far, and their daily stresses. Each session was taught by a registered Mindfulness-Based Cognitive Therapy facilitator. Participants in this condition were asked not to participate in any additional mindfulness activities (e.g., MBSR, yoga, meditation) throughout the duration of the training to ensure a similar level of exposure to mindfulness training across participants; however, factors such as exercise, diet, the number of hours practiced, and whether the participant performed during the training were not controlled for.

fMRI Procedure

Participants underwent the 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-

channel head coil. To examine participants' brain activity at rest, participants laid immobile in the scanner for 5 minutes and 9 seconds. They were told, "Relax and try not to think about anything in particular. Keep your eyes closed until the scan is over. The scan will take about 5 minutes." The resting state fMRI scan was performed with an echo planar pulse sequence, TR/TE 3000/27 ms, flip angle 90^o, FOV 24x24 cm^2, 64x64 matrix, slice thickness 3 mm, 48 axial slices, bandwidth 62.5 kHz. A conventional 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/TE 11.2/21 ms, flip angle 60°, field of view (FOV) 26x26 cm2, 256x256 matrix, slice thickness 1.5 mm) for further structural analyses. All participants underwent the same scanning procedure.

Data Analysis

Functional Connectivity Analysis

According to the literature, three resting state networks were investigated, including the default mode network (DMN), the salience network, and the Frontoparietal network (CEN; Melis, 2022). A seed-based functional connectivity (FC) approach was applied using the CONN toolbox v21.0 (www.nitrc.org/projects/conn, RRID:SCR_009550). For each network, the hub regions were selected as the seed (Table 1).

Table 1

Networks and Seed Selection

Brain networks	**Seeds selection**
Default mode network (DMN)	Medial prefrontal cortex (mPFC) Posterior cingulate cortex (PCC) Bilateral lateral parietal lobe (LP)
Salience network	Anterior cingulate cortex (ACC) Bilateral anterior insula

Frontoparietal network (CEN)	Anterior prefrontal cortex (anterior PFC) Bilateral prefrontal cortex (PFC) Bilateral posterior parietal cortex (PPC)

Functional image preprocessing was performed using the default pipeline in the CONN toolbox, including realignment, co-registration, and smoothing (6mm FWHM kernel). The default denoising pipeline in the CONN toolbox was applied to remove nuisance signals. Specifically, the signals from white matter and cerebrospinal fluid were regressed out by estimating five potential noise components (Chai et al., 2012). The Friston 24-parameter model was utilized to regress out head motion effects from the realigned data. Scrubbing was performed using artifact detection tools with the threshold for global-signal above 5 (z-value) and for subject-motion above 0.9 mm. In addition, linear and quadratic trends were also included as regressors since the BOLD signal exhibits low-frequency drifts. Temporal filtering (0.008–0.09 Hz) was then performed on the time series. To control for the effects of head motion differences across groups, the head motion and scrubbing parameters were included in the first level as covariates of interest. Using the seed-to-voxel FC analysis approach, the correlation coefficients between the time series of these seed regions and all other voxels in the whole brain were calculated and converted to z scores using Fisher's r-to-z transformation.

Group analysis

A 2 × 2 mixed model ANOVA analysis was conducted to examine the Group effect (i.e., Control vs. Mindfulness), Time effect (i.e., Pre-training vs. Post-training), and Group × Time interaction on the resting state networks' FC for each seed. The significance threshold was set as uncorrected $p < 0.005$ at the whole brain level, and FDR-corrected $p < 0.05$ at the cluster level. Post-hoc simple t-tests were performed using an ROI-to-ROI approach for the regions that showed significant main effects or interaction effects.

Results

Behavioural and Sociodemographic

There were no significant group differences in sex (5 females and 5 males in each group), age, whether participants had pre-existing psychological conditions, experience with mindfulness activities, age since starting music, number of years of music lessons, and number of hours of practice in adolescence or as a young adult. However, there were differences in the number of hours of practice currently, with the mindfulness group practicing more than the control group, $t(17) = 2.30$, $p = .034$.

Default mode network

mPFC-Seed FC

As shown in Figure 1A, at the whole-brain level, a significant group × time interaction effect was found for the mPFC-seed FC in the left vermis 6 (-8, -58, -20; $t(18) = 5.76$; $p_{FDR\text{-}cluster} = 0.017$). Further post-hoc simple tests revealed that the mindfulness group had decreased post-training FC ($t(9) = -8.00$; $p < 0.001$), while the control group had increased post-training FC ($t(9) =6.34$, $p < 0.001$) compared to the pre-training FC between the mPFC seed and the left vermis 6 (Figure 1B). Furthermore, during the post-training, the mindfulness group showed significantly lower FC than the control group ($t(18) = -10.47$, $p < 0.001$).

In addition, a significant group effect showed that the mindfulness group had greater FC between the mPFC seed and the right precentral gyrus (r.PreCG) (42, -10, 44; $t(18) = 4.86$; $p_{FDR\text{-}cluster} = 0.048$) compared to the control group (Figure2A). Further post-hoc tests revealed that the mindfulness group showed greater mPFC-r.PreCG FC than the control group at both pre-training ($t(18) = 4.37$, $p < 0.001$) and post-training ($t(18) = 4.37$, $p < 0.001$; Figure 2B).

Finally, significant time effects were also found for the mPFC-seed FC. As shown in Figure 3A**,** the time effects showed that post-training FC was greater than the pre-training FC in the right superior parietal lobule (r.SPL; 8, -68, 56; $t(18) = 4.20$, $p_{FDR\text{-}cluster} = 0.015$). Further post-hoc tests revealed that both the control group ($t(9) = 2.82$, $p = 0.02$) and mindfulness group ($t(9) = 5.42$, $p < 0.001$) showed greater mPFC-r.SPL FC in the post-intervention scan compared to the pre-intervention scan (Figure 3B).

Conversely, compared to the pre-training condition, the post-training condition showed decreased FC in the right superior frontal gyrus (r.SFG; 2, 46, -16; $t(18) = -6.81$, $p_{FDR\text{-}cluster} < 0.001$; Figure 3C) and the left temporal pole (l.TP; -52, 16, -16; $t(18) = -6.72$, $p_{FDR\text{-}cluster} < 0.001$; Figure 3D). Further post-hoc tests revealed that both the control group ($t(9) = -6.47$, $p < 0.001$) and mindfulness group ($t(9) = -4.06$, $p = 0.003$) showed decreased mPFC-r.SFG FC in the post-training scan (Figure 3E). For the FC between the mPFC and l.TP, both the control group ($t(9) = -4.77$, $p = 0.001$) and the mindfulness group ($t(9) = -6.24$, $p < 0.001$) showed significantly decreased FC during the post-training scan compared to pre-training scan (Figure 3F).

PCC-Seed FC

For the PCC-seed FC, only a significant time effect was found in the left central opercular cortex (l.C-Op; -52, -34, 6), with decreased FC during the post-training scan compared to the pre-training scan ($t(18) = -4.97$; $p_{FDR\text{-}cluster} = 0.013$; Figure 4A). Post-hoc tests showed that both the control group ($t(9) = -5.32$, $p < 0.001$) and the mindfulness group ($t(9) = -6.51$, $p < 0.001$) had decreased post-training FC (vs. pre-training; Figure 4B).

LP-Seed FC

Neither a significant main effect nor an interaction effect was found for the LP-seed FC.

Salience Network

Among three seeds within the Salience Network, only a significant time effect was found for the bilateral insula-seed FC in the right frontal pole (r.FP; 28, 50, 24). Specifically, the post-training FC was lower than the pre-training FC ($t(18) = -5.61$; $p_{FDR\text{-}cluster} = 0.002$; Figure 5A). Post-hoc tests revealed lower post-training FC in both the control group ($t(9) = -5.42$, $p < 0.001$) and the mindfulness group ($t(9) = -3.38$, $p = 0.008$) compared to the pre-training FC (Figure 5B).

CEN network

Lateral PFC-Seed FC

A significant group × time interaction effect was found for the bilateral lateral PFC-seed FC in the bilateral cerebellum crus II (0, -78, -34; $t(18) = 2.28$; p_{FDR}-cluster = 0.047; Figure 6A). Post-hoc analyses revealed that the control group ($t(9) = 7.04$, $p < 0.001$) showed increased FC, while the mindfulness group ($t(9) = -4.38$, $p = 0.002$) showed decreased FC during the post-training scan compared to the pre-training scan. Furthermore, during the post-training scan, the mindfulness group showed significantly lower FC than the control group ($t(18) = -6.24$, $p < 0.001$). No such group difference was found for the pre-training scan ($t(18) = 1.32$, $p = 0.20$; Figure 6B).

In addition, the significant time effects showed decreased post-training FC (versus pre-training) for the bilateral lateral PFC seed in the superior frontal gyrus (SFG; 4, 48, 34; $t(18) = -5.01$, p_{FDR}-cluster = 0.022; Figure 7A) and the right middle frontal gyrus (r.MFG; 42, 20, 34; $t(18) = -5.89$, p_{FDR}-*cluster* = 0.022; Figure 7B). Post-hoc tests revealed that both the control ($t(9) = -4.98$, $p < 0.001$) and mindfulness group ($t(9) = -5.67$, $p < 0.001$) showed decreased post-training lateral PFC-SFG FC compared to the pre-training scan (Figure 7C). Similarly, both the control ($t(9) = -3.64$, $p = 0.005$) and mindfulness group ($t(9) = -4.03$, $p = 0.003$) showed decreased post-training lateral PFC-r.MFG FC compared to the pre-training scan (Figure 7D).

PPC-Seed FC

For the PPC-seed FC, only a significant time effect was found in the left inferior frontal gyrus (l.IFG; -50, 26, -6), with decreased FC during the post-training scan compared to the pre-training scan ($t(18) = -5.27$, p_{FDR}-cluster < 0.001; Figure 8A). Post-hoc tests showed that both the control group ($t(9) = -5.79$, $p < 0.001$) and the mindfulness group ($t(9) = -3.09$, $p = 0.013$) had decreased post-training FC (Figure 8B).

Discussion

This study examined the resting state functional connectivity (rsFC) of areas of the default mode network (DMN), salience network (SN), and central executive network (CEN) in musicians with music performance anxiety (MPA) before and after a brief mindfulness training program. FC changes were found in both the mindfulness and control groups in various regions within these networks, with the most notable changes in the mindfulness group within the cerebellum.

The cerebellum has been shown to play a role in several sensorimotor, autonomic, cognitive, and emotional functions (Beuriat et al., 2022; Petrosini et al., 2022). The core emotional processing system includes connections within cortico-striatal-thalamic loops with structures, such as the PFC, amygdala, and hippocampus, with other subcortical structures, including the basal ganglia, thalamus, and striatum (Beuriat et al., 2022). Each of these regions is functionally and/or anatomically directly or indirectly connected to the cerebellum, which may underlie the cerebellum's ability to influence affective processing.

The cerebellar vermis, especially the posterior vermis (which includes vermis 6), has been shown to be involved in more "limbic" tasks through these feedback loops involving cortical, subcortical, limbic, and cerebellar structures (Benagiano et al., 2018; Stoodley & Schmahmann, 2010). Previous studies have demonstrated the cerebellum's ability to modulate the firing patterns of limbic structures, such as the amygdala and hippocampus, and vermis activation is exhibited in response to intense emotional states, such as panic and grief (Stoodley & Schmahmann, 2010).

In the present study, participants who underwent mindfulness training exhibited decreased rsFC between the mPFC and the vermis 6, while the control participants exhibited increased rsFC between the mPFC and the vermis 6. The cerebellum, specifically the vermis, has been linked to anxiety through its connections to the limbic system. For example, previous studies have documented that FC between the amygdala and cerebellum are increased in patients with GAD and other anxiety-related disorders, such as social anxiety disorder and obsessive-compulsive disorder (Chin & Augustine, 2023). rsFC has also been examined between the amygdala and mPFC. A study by Kim et al. (2011) demonstrated decreased rsFC between the dmPFC and the amygdala in a low anxiety group, suggesting that this represents "efficient mPFC-amygdala crosstalk … mitigating the generation of anxious states." Taken together, perhaps decreased FC between the mPFC and cerebellum in the mindfulness group and increased FC in the control group is a result of a cerebellar-amygdala-cortical feedback loop, in which there is less communication between these structures within the mindfulness group and more communication within the control group. These findings may demonstrate the influence of mindfulness on emotional processing through cortical and limbic brain regions. Lower subjective MPA levels from pre-training to post-training in the mindfulness group support this finding

(Boileau et al., in review). There were no changes in subjective MPA from pre-training to post-training in the control group, perhaps demonstrating consistent levels of high MPA and "inefficient mPFC-amygdala crosstalk" without intervention.

rsFC changes were also found between the lateral PFC (CEN) and the bilateral cerebellum crus II from pre- to post-training in both groups. More specifically, the mindfulness group showed decreased FC between these two regions, while the control group showed increased FC between these regions. Increased acceptance as a result of undergoing mindfulness training may have altered the FC between these regions. To support this interpretation, Goldin et al. (2019) examined participants' neural activity by asking participants to react to negative self-beliefs and to then implement acceptance strategies. They found that acceptance (a fundamental component of mindfulness), in comparison to reacting to negative self-beliefs, was associated with less neural activity in the lateral PFC and cerebellum. On the contrary, participants who reacted to negative self-beliefs exhibited more activity in the frontopolar medial PFC and bilateral cerebellum. The control group in the current study may have exhibited negative self-appraisals as opposed to accepting themselves and the situation with nonjudgement. Subjective MPA levels may elucidate these findings: The mindfulness group exhibited decreased subjective MPA levels from pre-training to post-training, whereas the control group showed no differences (Boileau et al., in review). As a result of mindfulness training, the mindfulness group may have learned acceptance strategies in response to music performance. The control group, however, may have continued to exhibit negative self-appraisals.

The present study also found decreased FC between the mPFC (DMN) and the right superior frontal gyrus and left temporal pole; between the PCC (DMN) and the left opercular cortex; between the bilateral insula (SN) and the right frontal pole; between the bilateral lateral

PFC (CEN) and the superior frontal gyrus and right middle frontal gyrus; and between the PPC (CEN) and the left inferior frontal gyrus in both the mindfulness and control groups at post-training. Decreased FC between these regions during the second scan may be due to being more comfortable in the MRI environment. The first MRI scan involved a novel experience that can elicit anxiety, but the participants would know what to expect during the second scan, perhaps reducing the communication between these regions.

In support of this interpretation, there was increased FC between the mPFC (DMN) and the right superior parietal lobule from pre-to post-training in both the mindfulness and control groups. The increased FC between these two regions at post-training may indicate that undergoing the second MRI scan was a more pleasant experience, as both the mPFC and right superior parietal lobule are activated in response to pleasant emotional states (Campagne et al., 2016; Sambuco et al., 2022).

In the present study, a significant group effect was also found. The mindfulness group had greater FC between the mPFC and the right precentral gyrus than the control group at both pre-training and post-training. This may be due to lack of randomization to the mindfulness and control groups. It is possible that the first ten participants who enrolled in the study, who were allocated to the mindfulness group, were more motivated to participate in the study to reduce their performance anxiety by becoming more mindful. A study by Seo et al. (2013) demonstrated that the right precentral gyrus is activated in response to positive, rewarding stimuli, which have been shown to elicit increased motivation in relation to appetitive goals and increased psychomotor action towards achieving these goals (Lang, 2010; Roesch & Olson, 2003). Considering this, future studies should randomly allocate participants to the conditions. Although the most significant limitation of this study was sample size – there were only ten participants in each condition – this study is in line with similar studies that examine the effects of mindfulness training on MPA and/or brain activity (Gómez-López & Sánchez-Cabrero, 2023; Young et al., 2018). In addition, participants in the mindfulness condition completed the mindfulness training as a group, whereas those in the control condition did not. Therefore, some of the changes in rsFC in the mindfulness group may be partly due to the influence of group cohesion and social support, which has been suggested as a possible change mechanism of mindfulness-based interventions (Blanck et al., 2018). Future studies should include an active control group, as this study only employed a passive control group. There were also differences in the number of hours that the musicians currently practice music, with the mindfulness group practicing more than the control group. However, a recent study demonstrated no effect of hours practiced weekly on MPA in a global sample of adolescents, which is consistent with previous studies (Papageorgi, 2022). It must also be noted that this study recruited young adult musicians. Some studies have found that younger, undergraduate musicians report higher levels of MPA than professionals (Papageorgi et al., 2013; Fernholz et al., 2019); thus, the results from this study should not be generalized to other groups. Finally, performance quality was not measured in this study. Lin et al., (2019) observed that daily individual meditation practice reduced MPA and increased performance quality in higher education students; however, the relationship between MPA, performance quality, and rsFC remains unexplored.

Although this study has limitations, it also has several strengths. First, the study design is a strength because it is in line with other studies employing a longitudinal mindfulness training program (Tang et al., 2015). The mindfulness intervention's brevity is also a strength. Neurophysiological changes in rsFC were observed after only two weeks of mindfulness training. This is important to note because typical mindfulness training programs are eight weeks long. Although an eight-week program may offer different benefits, this study demonstrates that brief mindfulness training may be an accessible and cost-efficient alternative. Follow-up of these participants to observe continued benefits of the mindfulness intervention is also important. MPA is debilitating; however, it is sometimes viewed as “inherent to the profession and/or musical training” (Gómez-López & Sánchez-Cabrero, 2023). Musicians under 30 years of age are more likely to experience MPA, perhaps as a result of less performing experience (Biasutti, & Concina, 2014) or burnout (Bernhard, 2010). However, there is little focus on the diagnosis and prevention of MPA. This may lead young musicians to abandon their musical careers as their MPA increases without intervention. In addition, the normalization of using drugs to alleviate MPA points to the need for healthier options. Mindfulness may help address these issues.

Conclusion

Mindfulness, concisely, is paying attention to the present moment nonjudgmentally. The findings from this study demonstrate that even brief mindfulness training influences communication between regions of several important neural networks (DMN, SN, and CEN) within musicians with performance anxiety. Most notably, brief mindfulness training leads to FC changes between the areas of the PFC and areas of the cerebellum. These changes may indicate increased acceptance of the present moment as a result of the mindfulness training. This suggests that further research is needed to examine the potential relationship between different facets of mindfulness, such as acceptance, and brain communication. It also suggests that mindfulness may be a useful tool to address the deleterious effects of MPA.

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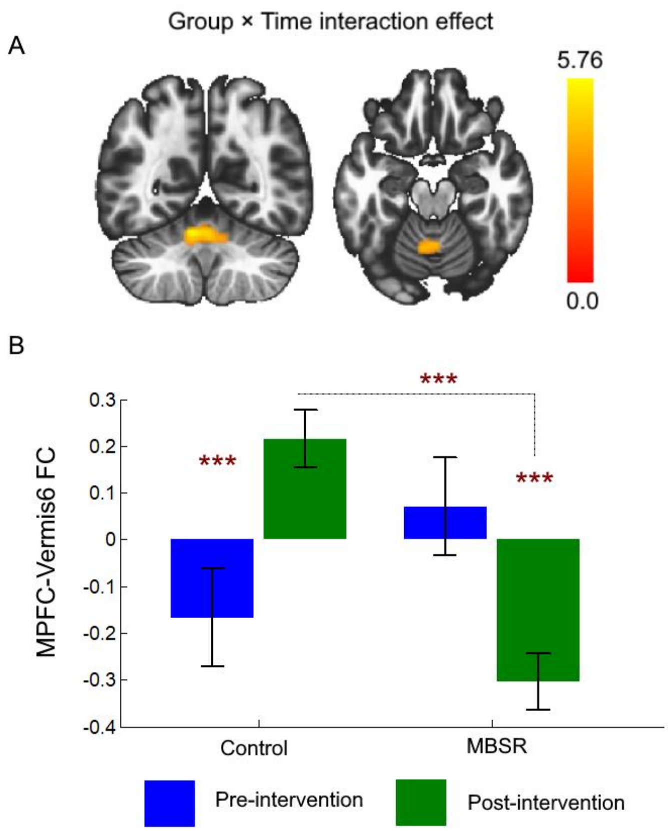
Figure 1

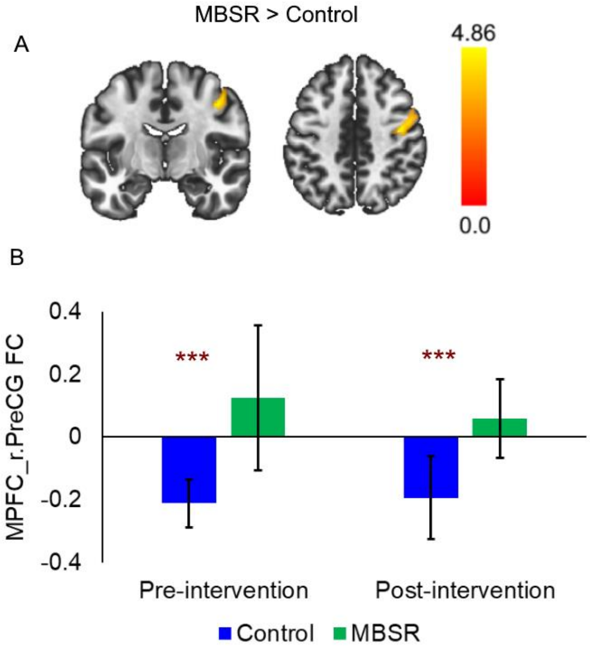
Group × Time Interaction Effect of FC Between the mPFC Seed and the Vermis 6



Note. (A) The interaction effect at the whole brain level (whole brain uncorrected $p < 0.005$; p_{FDR} cluster < 0.05); (B) Post-hoc simple tests on each level. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Figure 2

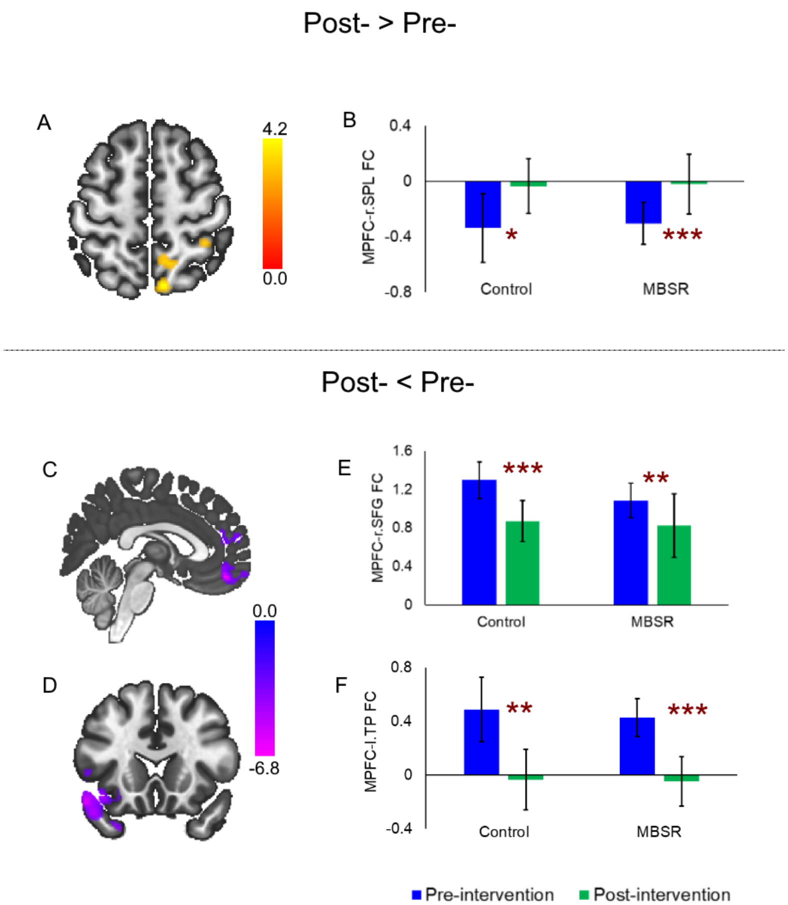
Group Effect of the FC Between the mPFC seed and the Right Precentral Gyrus



Note. (A) The Mindfulness group showed greater FC than the Control group at the whole brain level; (B) Post-hoc simple tests to examine the group effect for each scan session. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Figure 3

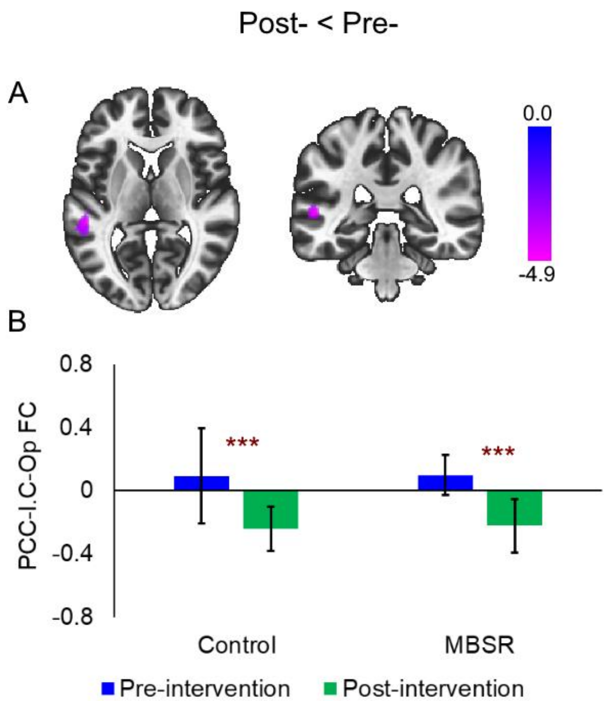
Time Effects of the mPFC-Seed FC



Note. (A) Greater post-training (vs. pre-training) FC between the mPFC seed and the r.SPL at the whole brain level; (B) Post-hoc tests showed both the Control and Mindfulness groups had greater post-training (vs. pre-training) FC between the mPFC seed and r.SPL. Decreased post-training (vs. pre-training) FC between the mPFC seed and the (C) r.SFG and (D) left temporal pole (l.TP) at the whole brain level; post-hoc tests showed both the Control and Mindfulness groups had decreased post-training (vs. pre-training) FC between the mPFC seed and (E) the r.SFG and (F) l.TP. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Figure 4

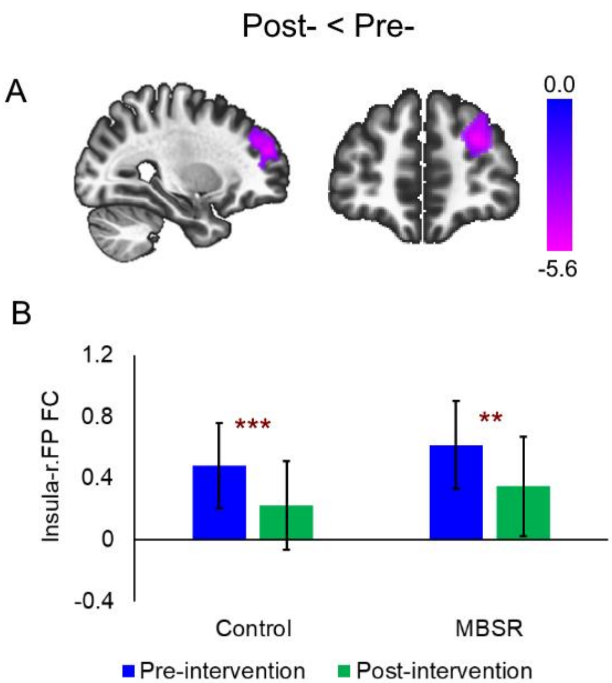
Time Effect of the PCC-Seed FC



Note. (A) Decreased post-training (vs. pre-training) FC between the PCC seed and the left central opercular cortex (l.C-Op). (B) Post-hoc tests showed both the Control and Mindfulness groups had decreased post-training (vs. pre-training) FC between the PCC seed and l.C-Op * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Figure 5

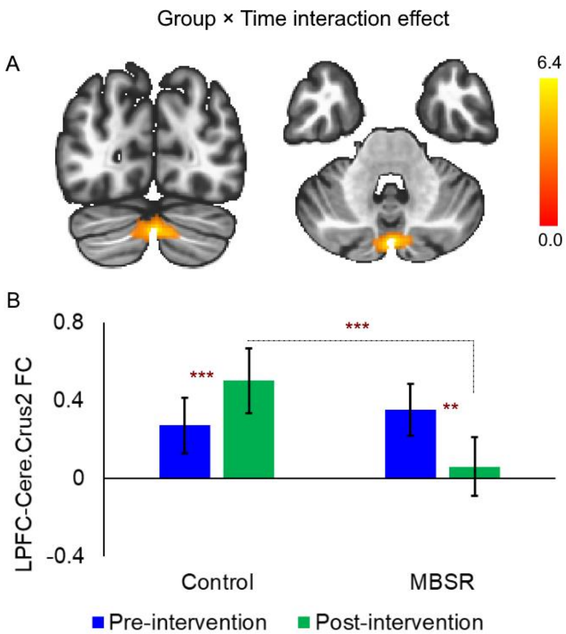
Time Effect of the Bilateral Insula-seed FC



Note. (A) Decreased post-training (vs. pre-training) FC between the bilateral insula seed and the right frontal pole (r.FP). (B) Post-hoc tests showed both the Control and Mindfulness groups had decreased post-training (vs. pre-training) FC between the bilateral insula seed and the r.FP. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Figure 6

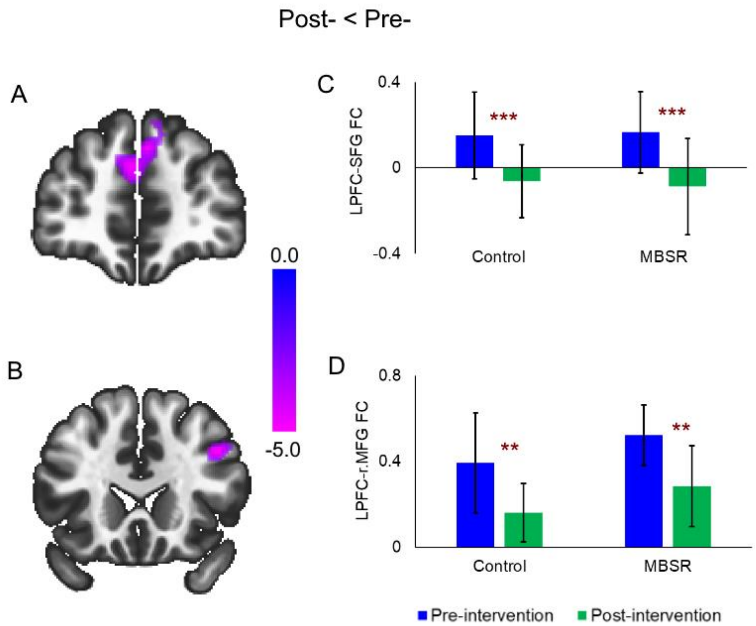
Group × Time Interaction Effect of FC Between the Bilateral Lateral PFC Seed and the Cerebellum Crus2 (Cere.Crus2)



Note. (A) The interaction effect at the whole brain level; (B) Post-hoc simple tests on each level. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Figure 7

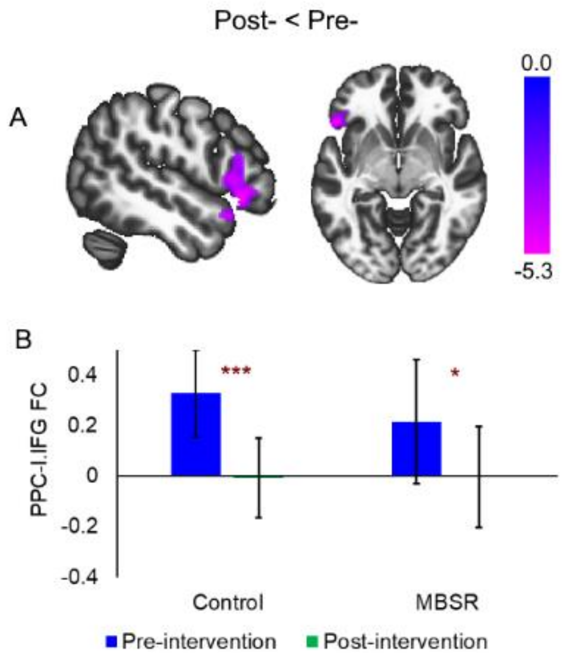
Time Effects of the Lateral PFC-Seed FC



Note. Decreased post-training (vs. pre-training) FC between the lateral PFC seed and the (A) SFG and (B) r.MFG at the whole-brain level; post-hoc tests showed both the Control and Mindfulness groups had decreased post-training (vs. pre-training) FC between the lateral PFC seed and the (C) SFG and (F) r.MFG. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Figure 8

Time Effect of the Bilateral PPC-Seed FC



Note. (A) Decreased post-training (vs. pre-training) FC between the PPC seed and the r.IFG. (B) Post-hoc tests showed both the Control and Mindfulness groups had decreased post-training (vs. pre-training) FC between the PPC seed and r.IFG * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

CHAPTER FIVE: General Discussion

The purpose of this dissertation was to investigate the effects of brief mindfulness training on subjective anxiety levels and neurophysiological correlates of mindfulness within musicians with MPA. Theories on attention and emotion regulation were utilized to examine mindfulness' effects on subjective anxiety levels and brain regions related to stress (Study 1), its effects on executive functioning, specifically working memory (Study 2), and its effects on communication between brain regions (Study 3). Overarchingly, the results suggest that mindfulness positively influences psychological and neurophysiological aspects of MPA. Specifically, mindfulness alleviates subjective anxiety, changes neural activity in brain regions related to the stress response, enhances neurophysiology during working memory, and demonstrates more efficient communication between brain regions. Hypotheses that attention and emotion regulation mechanisms underly these findings are supported.

Main Findings: Study 1

One of the objectives of Study 1 was to validate an anxiety-provoking social-evaluative fMRI task that consisted of musicians with MPA watching themselves or someone else play an instrument while in the MRI scanner. Creating and validating this type of task was necessary as there are no anxiety-provoking social-evaluative tasks that are utilized with fMRI to measure MPA in musicians. This type of task is necessary to determine how MPA is portrayed in the scanner in real time. Neurophysiological results indicated that the task elicited neural activity changes in brain regions associated with emotion regulation (i.e., middle frontal gyrus) and self-evaluation under threat (i.e., orbitofrontal cortex). Higher activity in these brain regions is expected when undergoing an anxiety-provoking stimulus (e.g., watching themselves play), such that these regions would exhibit lower activity when watching a non-threatening stimulus (e.g., watching someone else play). Further, this activity seems to have consumed neural resources so that less activity was then available in other regions related to visual processing and inhibitory behaviour when participants watched themselves play versus watching someone else play. These findings suggest that the anxiety-provoking social-evaluative fMRI task was effective in eliciting stress responses.

Another objective was to examine how brief mindfulness training influences subjective anxiety and neural activity in areas related to attention and emotion regulation during the fMRI task. After brief mindfulness training, the mindfulness group decreased in subjective anxiety scores from baseline to post-training, whereas the control group did not. When examining the association between mindfulness training and neural activity, mindfulness training was associated with increased activity in areas related to attention (e.g., thalamus, right superior parietal gyrus, inferior parietal lobule, supramarginal gyrus, dorsolateral PFC, substantia nigra) and emotion regulation (e.g., dorsolateral PFC, left amygdala). Previous fMRI studies have found that mindfulness training is associated with brain regions related to attention, specifically in areas related to alerting, orienting, and executive neural networks (Malinowski, 2013; Marchand, 2014; Posner & Rothbart, 2007; Wadden et al., 2018). Neural activity in this study was related to changes in these neural networks, which suggests that the musicians' attentional abilities increased in response to brief mindfulness training. This change in attentional abilities may also help to improve emotion regulation, reflected in dorsolateral PFC and left amygdala activity. The control group increased in neural activity in areas related to visuo-motor (e.g., precentral gyrus, cuneus) and auditory (e.g., Heschel's gyrus) processing and in processing sensory information from the body (e.g., postcentral gyrus). These changes may be a result of sensitization of potentially negative sensory stimuli. Finally, at time 2, the mindfulness group exhibited greater activity in the dorsolateral PFC, an area implicated in both attention and emotion regulation processes, whereas those in the control group did not. Altogether, these findings suggest that attention and emotion regulation processes underly the associations between mindfulness and brain regions related to stress responses. These results are especially influential for musicians with MPA as these processes are integral for their performance and overall wellbeing.

Main Findings: Study 2

Study 2 examined the association between mindfulness and working memory pre- and post-training, using the letter n-back task, in musicians with MPA. First, performance results demonstrated that the control group had slower reaction times from time 1 to time 2, and they had slower reaction times than the mindfulness group at time 2. These performance-related results may indicate improved attention in the mindfulness group during the task, as they were able to do the task quicker than the control group. Although quicker, there were no differences between the mindfulness group and control group in commission or omission errors. Thus, the mindfulness group was more efficient without sacrificing accuracy.

Regarding neural activity, participants in the mindfulness group exhibited decreased activity at time 2 when compared to time 1 in the right middle frontal gyrus (i.e., the dorsolateral PFC), which is involved in monitoring (i.e., actively retaining) and manipulating (i.e., updating or selecting) items in working memory. There was also decreased activity in the right supplementary motor area, which is involved in temporarily sustaining and manipulating information (Cañas et al., 2018). The control group did not exhibit any differences.

In addition, there were no differences between the groups at time 1; however, there were group differences at time 2: the mindfulness group demonstrated significantly less activity than the control group in the bilateral lingual gyri, an area involved in visual processing. The mindfulness group also demonstrated less activity in the bilateral middle occipital gyri (which covers parts of the precuneus/posterior cingulate cortex and cuneus) and in the right cuneus. As the cuneus is implicated in directing attention to internal processing, such as self-referential processing, these results may indicate that mindfulness leads to increased mindful awareness and fewer attentional resources toward self-referential processes. These neurophysiological and performance-related results suggest that mindfulness training contributes to improved attention during the task.

Main Findings: Study 3

Study 3 examined the resting state functional connectivity (rsFC) of areas in the default mode network, the salience network, and the central executive network in musicians with MPA before and after brief mindfulness training. First, participants who underwent mindfulness training exhibited decreased rsFC between the medial PFC (default mode network) and the vermis 6, a posterior region of the cerebellum, whereas the control participants exhibited increased rsFC between the medial PFC and the vermis 6. The cerebellum and medial PFC are part of a cerebellar-amygdala-cortical feedback loop, with a recent study documenting increased rsFC between the cerebellum and the amygdala in patients with GAD and other anxiety disorders (Chin & Augustine, 2023). Another study (Kim et al., 2011) found decreased rsFC between the dorsomedial PFC and the amygdala in a low anxiety group. These findings may support the notion of medial PFC-amygdala-cerebellar crosstalk within the mindfulness group, demonstrating mindfulness' influence on emotional and cortical brain regions.

Second, mindfulness showed decreased rsFC between the lateral PFC (central executive network) and the bilateral cerebellum crus II, whereas the control group showed increased FC between these regions. Perhaps mindfulness, specifically acceptance – a fundamental component of mindfulness – was associated with less neural activity in the lateral PFC and cerebellum. This was supported by Goldin et al. (2019) who found that acceptance, in comparison to reacting to negative self-beliefs, was associated with less neural activity in the lateral PFC and cerebellum, whereas participants who reacted to negative self-beliefs exhibited more activity in the frontopolar medial PFC and bilateral cerebellum. Due to mindfulness training, the mindfulness group may have learned acceptance strategies in response to music performance, whereas the control group may have continued to exhibit negative self-appraisals.

This study also found differences in regions related to novel experiences. For example, there was increased rsFC between the medial PFC (default mode network) and the right superior parietal lobule from pre- to post-training in both the mindfulness and control groups. This finding may indicate that the MRI was a more pleasant experience at time 2, as these regions are activated in response to pleasant emotional states (Campagne et al., 2016; Sambuco et al., 2022).

In addition, the mindfulness group had greater rsFC between the medial PFC and right precentral gyrus than the control group at time 1 and time 2. Perhaps those in the mindfulness group were more motivated to join the study, as the study did not randomly assign participants to the groups. Indeed, a study by Seo et al. (2013) showed that the right precentral gyrus is activated in response to positive stimuli, which may elicit increased motivation and psychomotor actions towards achieving goals (Lang, 2010; Roesch & Olson, 2003).

Theoretical and Practical Implications

As demonstrated, there are key brain regions implicated in attention and emotion regulation processes. Areas located in the PFC are easily identifiable as important for increased attention and emotional processes foundational to the neurophysiological mechanisms of mindfulness. The PFC can be functionally divided into three parts, two of which are of particular interest to this study and will be described below. The PFC consists of the lateral PFC, including the ventrolateral PFC and the dorsolateral PFC, and the medial PFC, including the ventromedial PFC and the dorsomedial PFC. The lateral PFC is especially important in attention processes.

The dorsolateral PFC, for example, plays a role in sustaining and monitoring the focus of attention and updating goal-relevant information by inhibiting behaviourally irrelevant information (Tomasino & Fabbro, 2016). Musicians with MPA may exhibit poor attention and concentration. An example of this is when a musician is concerned about making a mistake when performing, which could potentially lead to a memory lapse. The musician may then expect that they would forget the music in the future, creating a cyclical stress response. Better inhibition, however, could help musicians by suppressing this salient negative stimulus, allowing them to focus on the task at hand.

The ventrolateral PFC also plays a role in attention processes. Diamond (2016) argues that there are three executive functions (with two described in this study), including inhibitory control and working memory. The ventrolateral PFC plays a role in inhibitory control through its ability to select and process sensory perceptual stimuli according to the outcome value. It is also involved in working memory processes, as it is implicated in selecting and manipulating information. As a result of improved attentional control due to mindfulness training, musicians may experience less emotional interference during a performance, allowing them to sufficiently focus on task-relevant goals.

These two brain regions are also central to emotion regulation processes. The ventrolateral PFC is directly connected to the amygdala and is thought to modulate the amygdala's response to threatening stimuli, and the dorsolateral PFC is involved in the perception and control of emotional experiences. This study found increased activity in the dorsolateral PFC and in the left amygdala, an area that is primarily involved in cognitively controlled emotional processing (Barreiros et al., 2019). In addition, rsFC changes were found after brief mindfulness training. Specifically, the mindfulness group showed decreased rsFC between the lateral PFC and the bilateral cerebellum crus II. When examining the mindfulness group's subjective MPA levels, the mindfulness group exhibited decreased subjective MPA levels from pre- to post-mindfulness training. These findings may demonstrate increased acceptance (again, a fundamental component of mindfulness) as a result of mindfulness training, as Goldin et al. (2019) demonstrated that acceptance was associated with less neural activity in the lateral PFC and cerebellum in a recent study. Increased acceptance as a result of mindfulness training may allow musicians to view their performances as acceptable and challenging, rather than appraising the performance as negative and threatening, possibly increasing musicians' wellbeing and quality of life.

The medial PFC, including the ventromedial PFC and the dorsomedial PFC, is also important in emotion regulation and attention processes. The medial PFC plays a role in the perception of a stimulus through appraisal and reappraisal of one's interpretation of the stimulus and its relevance to the self, especially with social evaluative processes (Menon & D'Esposito, 2021). Musicians may perceive musical performances as inherently social evaluative. The medial PFC is involved in perceiving stimuli during performances as either threatening or challenging to the self. Indeed, the ventromedial PFC, in particular, is involved in threat and reward processing through modulation of amygdala activity, a critical brain region in threat detection and response. The dorsomedial PFC is also involved in stimulus perception, especially to perceptions of social stimuli relating to the self. As musical performances are often social evaluative, mindfulness training may help musicians to become meta-aware, allowing the musician to consciously observe feelings related to a performance as temporary, rather than a reflection of the self (Bennett et al., 2021).

Both the ventromedial and dorsomedial PFC are involved in attentional engagement and disengagement. The ventromedial PFC, which is part of the default mode network, is involved in task negative/stimulus-independent thought, including mind wandering. Whereas the dorsomedial PFC, which is part of the central executive network, is involved in attentional disengagement from threatening stimuli by re-orienting and directing attention away from potentially threatening stimuli. During mindfulness, the default model network is activated, and the mind starts to wander, possibly towards a potentially distressing thought. The salience network recognizes the mind wandering, and the central executive network lets go of the thought through attentional disengagement (Malinowski, 2013).

Other brain regions also exhibited increased neural activity after mindfulness training, including the thalamus, right superior parietal gyrus, inferior parietal lobule, the supramarginal gyrus, and the substantia nigra. All of these areas play a role in attentional processes associated with mindfulness in the literature. For example, the thalamus and right superior parietal gyrus are part of the alerting neural network, which is related to sustained attention on an object, such as one's breathing. When one's thoughts begin to wander, the substantia nigra, part of the salience network (Menon & D'Esposito, 2022), detects the wandering thought. The executive control network lets go of the wandering thought. The supramarginal gyrus and inferior parietal lobule, part of the orienting neural network, then shift attention back to one's breathing (the executive control neural network is also activated with this shift in attention; Malinowski, 2013).

The neurophysiological and performance-related results from the mindfulness group are suggestive of more efficient working memory processing. More specifically, this was observed with a reduction in neural activity in the right middle frontal gyrus (dorsolateral PFC) and the supplementary motor area, suggesting fewer cognitive resources necessary for the task at hand. Decreases in neural activity in the supplementary motor area may signify less reliance on motor traces, which are "imagined motor representations of salient external or internal information in the absence of overt [movement]" (Leisman et al., 2016 as cited in Marvel et al., 2020, p. 8), and can be used in working memory processes, such as holding a stimulus (e.g., a letter) in the mind without saying it aloud. Neural activity in the cuneus is also linked to attention, namely to internally directed attention (Benedek et al., 2016). Mindfulness training may have led to decreased activation of the cuneus due to the allocation of fewer attentional resources to self-referential processes, and more attention to the task at hand. In addition, the mindfulness group had significantly quicker reaction times than the controls at time 2 during the n-back task, with no concomitant increase in errors, suggesting better working memory processing in the mindfulness group. Working memory is essential for many musical activities, such as listening attentively to music and responding, visual aspects such as reading music notation, and motor skills (Pozenatto, 2020). Better working memory as a result of mindfulness training may allow musicians to better perform these skills, all the while requiring less attentional effort in doing so and increasing cognitive capacity to perform relevant tasks necessary for musical performances.

Another brain region related to emotion regulation is the cerebellum, which is directly or indirectly connected to the PFC, amygdala, and other brain regions related to emotion regulation. The cerebellar vermis has been shown to be involved in feedback loops between cortical, subcortical, limbic, and other cerebellar structures (Benagiano et al., 2018; Stoodley &

Schmahmann, 2010). Indeed, the cerebellum has been shown to modulate firing patterns of limbic structures, and vermis activation has been shown in response to intense emotional states (Stoodley & Schmahmann, 2010). The cerebellum's influence on anxiety may be due to its link to the limbic system. A cerebellar-limbic-cortical feedback loop may help explain this. Previous studies have found increased rsFC between the amygdala and cerebellum in individuals with GAD and other anxiety-related disorders (Chin & Augustine, 2023). Kim et al. (2011) also found decreased rsFC between the dorsomedial PFC and the amygdala in a low anxiety group. Both of the studies' findings demonstrate "[medial] PFC-amygdala crosstalk." In the current study, the mindfulness group exhibited decreased rsFC between the medial PFC and cerebellum and between the lateral PFC and cerebellum, suggesting that there is less communication between these structures and more "efficient [medial] PFC-amygdala crosstalk." Decreased rsFC between PFC regions and the cerebellum after mindfulness training may suggest an alleviation of MPA in musicians. These findings reflect a more efficient cerebellar-limbic-cortical feedback loop, which is thought to underlie anxiety and anxiety-related disorders.

Altogether, changes in neural activity, behavioural indices, and subjective anxiety levels point to brief mindfulness training as useful for musicians with MPA. Mindfulness' effects on attention and emotion regulation processes, and the brain regions associated with them, are well-observed in this study. The positive effects of mindfulness training for musicians with MPA may expand beyond their musical performances and into their overall professional and personal lives as well.

Strengths, Limitations, and Future Directions

This study examined the psychological and neurophysiological effects of brief mindfulness training in musicians with MPA and had many strengths. First, this study is the first of its kind to assess the influence of brief mindfulness training on psychological, neurophysiological, and behavioural factors associated with MPA using a comprehensive approach to do so. Further, this study contributes to the literature on mindfulness in general and to the literature on the relationship between mindfulness and MPA. Importantly, the practical implications of mindfulness on MPA may also influence a myriad of cognitions (e.g., self-talk, memory lapses) and behaviours (e.g., working memory reaction times) affected by MPA.

Second, there are several methodological strengths, such as the brevity of the mindfulness training and the pre-post design. After only two weeks of mindfulness training, significant psychological (i.e., subjective anxiety levels) and neurophysiological changes in musicians with MPA were found. Traditional MBSR programs are eight weeks long, and although they may demonstrate different changes than our results, this demonstrates that brief mindfulness training could be efficacious to alter indications of MPA (i.e., subjective anxiety levels). Additionally, all participants learned mindfulness techniques from the same instructor, during the same group, which ensured consistency within and between participants, thereby enhancing external reliability and reducing the likelihood that the effects of mindfulness were due to instructional differences. The effects of mindfulness training on musicians with MPA was examined longitudinally. Currently, there is a shift away from cross-sectional study designs to longitudinal study designs, so this study is in line with other recent studies that examine the neurophysiological mechanisms of mindfulness (Malinowski, 2013; Tang et al., 2015). Third, this study validated a social-evaluative anxiety-provoking fMRI task to measure MPA. This task is meant to reflect the anxiety felt by musicians with MPA as they perform and is the first of its kind to do so. No study has created and validated an fMRI task that examines neural activity in real time in musicians with MPA. In addition, this task may be altered to apply to other types of performance anxiety, such as in sports.

The most significant limitation is sample size – there were only ten participants in each group. Due to the small sample size, there was low power, which lessens our ability to confidently interpret the results. In addition, due to low sample size, we were not able to conduct analyses of gender or sex differences, differences in the type of instrument played, and differences in the length of time playing music. However, our sample size is similar to those of other studies that examined the effects of mindfulness training on MPA and of studies that examined the effects of mindfulness on brain activity (Gómez-López & Sánchez-Cabrero, 2023; Young et al., 2018). Future studies should aim for larger sample sizes to optimize power and ensure the results are generalizable. Considering many musicians use substances to cope with MPA, this study should have rigorously screened for substance use before the scans. However, this study did not do so, and therefore, substance use may have altered participants' behavioural and emotional responses in the scanner. Another limitation is that participants were not randomly allocated to the control or mindfulness group. The first ten participants were allocated to the mindfulness group, while the next ten were allocated to the control group. It is plausible that participants in the mindfulness group may have been more motivated and/or interested to participate in the study to decrease their MPA as they were among the first to participate in the study. Random allocation to groups would have minimized the influence of individual differences, providing more internal validity and confidence that the results are indeed caused by the mindfulness training. This study also did not compare mindfulness training to an active control group, so future studies should do so, to control for group cohesion and group activity/social support, as these factors have been suggested as possible change mechanisms of mindfulness-based interventions (Blanck et al., 2018). Without an active control group, we cannot control for practice effects that are not due to the mindfulness training. In addition, compared to participants in the control group, participants in the mindfulness group allocated more time to the study and learned mindfulness in a group format.

We also found that participants in the mindfulness group currently practiced music for longer periods than participants in the control group. However, a recent study showed that there were no effects of hours practiced weekly in a sample of adolescents with MPA (Papageorgi, 2022). This may suggest that the amount of time that the musicians in this study practiced music does not influence their MPA. It must also be noted that their anxiety scores were higher in the mindfulness group than the control group at baseline. Although it may be possible that mindfulness is more effective for those with higher anxiety, it has been shown that mindfulness-meditation-based interventions demonstrated decreases from pre- to post-intervention at all levels of anxiety (Khoury et al., 2013). This suggests that the benefits of brief mindfulness training observed in our studies may be applicable to those with high and low MPA; however, caution when interpreting this finding is warranted. Another limitation related to subjective anxiety scores is that the sample size was low, so there is increased risk of type I error. Other limitations include lack of generalizability to different community populations, as some studies have found that younger, undergraduate musicians report higher levels of MPA than more experienced musicians (Papageorgi et al., 2013; Fernholz et al., 2019), and lack of measurement of performance quality. Lin et al., (2018) found that daily individual meditation practice reduced MPA and increased performance quality in higher education students; however, the relationship between performance quality, MPA, and neurophysiological changes was not examined in this study. Finally, future research should consider incorporating other psychological and cognitive indicators, such as the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), as sleep is integral to cognitive tasks such as reaction time, and the Adult ADHD Self-Report Scale (ASRS; Kessler et al., 2005), as results from this scale may point to differences in attention. In addition, future research should consider using the Kenny music performance anxiety inventory (KMPAI; Kenny, 2009), specifically the "self-management of music performance anxiety rating scale," in which musicians rank 18 strategies used to manage their MPA in effectiveness.

Summary

This study filled an important knowledge gap in our understanding of the relationship between brief mindfulness training and neural, behavioural, and psychological indicators of MPA. This dissertation established attention and emotion regulation processes, and associated brain regions, behavioural indices, and subjective anxiety levels, as integral to the mechanisms behind mindfulness. This study demonstrated that neural activity in brain regions related to attention and emotion regulation, including stress, are influenced by mindfulness training. Specifically, neural activity in response to a social-evaluative anxiety-provoking stress task was altered by mindfulness training. Behavioural indices of working memory were also influenced by mindfulness training, as well as subjective anxiety levels. A more comprehensive picture of the effects of mindfulness training on MPA would include measuring neural activity, subjective anxiety levels, and behavioural indices, in addition to measuring performance quality pre- and post-mindfulness training. Previous studies have shown that performance quality is affected by MPA (Simoens et al., 2015), and Kenny and Osborne (2006) found that MPA could greatly influence future performances as well. Although there are many possibilities for future studies incorporating the methods from this study, these results suggest that brief mindfulness training may be helpful in the near future. For example, mindfulness training could be used early on in musical training to help prevent MPA in less experienced musicians. In addition, this training may be helpful for others who undergo activities that may elicit performance anxiety, including sports, acting, and public speaking. Overall, this study suggests that brief mindfulness training is beneficial for musicians with MPA. We all love listening to music, so should we not make sure that musicians enjoy *making* music?

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