Pharmamusicology: Exploring the Impact of Music on the Physiology and Psychology of Anxiety Disorders and Well-Being

by

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Submitted to the Program in Media Arts and Sciences,
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MASTER OF SCIENCE

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Abstract

This thesis investigates and assesses the impact of personalized approaches to music-based mental health and well-being support systems grounded in physiology and/or psychology, through analysis of biometric and self-report data. This work is divided into two streams, with four projects classified into the category of "Music as Expression" and one as "Music as Intervention." The first project explores the impact of music composition and performance on self-reported well-being via a "well-being workshop" where participants reported that the music-based activity was engaging and beneficial. The following three projects explored the relationship between live music performance and well-being through data collection during the world premiers of *The Distance Between Us*, *Breathing Together*, and the pilot of the *Wellbeing Concerts at Carnegie Hall*. The *Wellbeing Concerts at Carnegie Hall* and *The Distance Between Us* projects yielded novel methods of audience surveyal, such as the "In-Concert Well-Being and Affect Survey (ICWAS)," that were informed by the exploratory findings from the performance of *Breathing Together*. The pilot data, while limited, demonstrates the promise of these approaches and calls for further study. While composing *The Distance Between Us*, I also created and used a method of health-informed notation that is included in this thesis, alongside an archival recording of this piece. Finally, the fifth project, titled "Investigating the Physiological and Psychological Effect of an Interactive Musical Interface for Stress and Anxiety Reduction," assesses the utility of music to reduce the physiological and psychological symptoms of anxiety. Pilot results show a significant reduction in self-reported stress, while self-reported anxiety and biometrics highlight further improvements for future protocols. Together, these five projects serve as first steps towards a nuanced understanding of personalized applications of music-based strategies for mental health and well-being promotion and assessment, highlighting important findings and implications for future research and practice.

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Contents

Abstract **3**

Acknowledgments **5**

1 Introduction **17**

2 Contributions **21**

3 Background and Prior Work **23**
3.1 Theoretical Definitions 23
3.2 The Physiology of Anxiety 25
3.3 Creativity and Mental Health 27
3.4 Characteristics of Anxiety-Reducing Music 29
3.5 Music, Physiology, and Mood 30
3.6 Cultural and Historical Relationships Between Music and Health 33
3.6.1 Sri Lanka: An Illustrative Example 35
3.7 Summary 38

4 Structural Outline **39**

5 Music as Expression **41**
5.1 Music and Well-Being Workshop 42
5.1.1 Workshop Structure ("Methods") 43
5.1.2 Attendee Feedback ("Results") 44
5.1.3 Discussion 46
5.2 Audience Response 47
5.2.1 *Breathing Together* 47
5.2.2 The *Wellbeing Concerts at Carnegie Hall* 51
5.2.3 *The Distance Between Us* 59
5.3 Conclusions 71

6 Music as Intervention **73**
6.1 Music, Stress, and Anxiety 74
6.1.1 Methods 76
6.1.2 Results 81
6.1.3 Discussion 83

6.1.4 Conclusion . . . 87

7 Limitations **89**

8 Future Work **91**
8.1 Music and PTSD . . . 91
8.2 Music and Anxiety: A Case for Personalization . . . 93
8.3 Clinical and Neurophysiological Research . . . 94
8.4 Generative Music . . . 95

9 Conclusion **97**

References **99**

A *Breathing Together* Audience Responses **113**
A.1 Question 1 . . . 114
A.2 Question 2 . . . 115
A.3 Question 3 . . . 116
A.4 Question 4 . . . 117
A.5 Question 5 . . . 118
A.6 Question 6 . . . 119

B In-Concert Well-Being and Affect Survey (ICWAS) **121**
B.1 Digital ICWAS Questions: April 16, 2023 Pilot . . . 122
B.1.1 Before-Concert Onboarding and Question . . . 122
B.1.2 Pause Screen . . . 123
B.1.3 During-Concert Question . . . 123
B.1.4 Pause Screen . . . 123
B.1.5 Post-Concert Question . . . 124
B.2 Printed, Hard Copy ICWAS Questions: May 23, 2023 Pilot . . . 125
B.2.1 Before-Concert Onboarding and Questions . . . 125
B.2.2 During-Concert Question . . . 126
B.2.3 Post-Concert Question . . . 126

C *The Distance Between Us* Score **127**

D *The Distance Between Us* Survey Responses **145**

E Music, Stress, and Anxiety – Pre-Study Questionnaire **151**
E.1 Demographics . . . 152
E.2 Current Anxiety and Stress (CAS) Questionnaire . . . 154
E.3 Generalised Anxiety Disorder Assessment (GAD-7) . . . 155

List of Figures

3-1 Chetan Walia's "Dynamic Definition of Creativity" 28

5-1 Photographic Documentation from the Music and Well-Being Workshop . . 43
5-2 Example of a MIDI Instrument from the Music and Well-Being Workshop . 44
5-3 Jessica Shand performing in *Breathing Together* 47
5-4 Examples of Stage Design for the *Wellbeing Concerts at Carnegie Hall* . . . 54
5-5 Photographic Documentation of the *Wellbeing Concerts at Carnegie Hall* . 57
5-6 Charlie Lovell-Jones and Jessica Shand performing *The Distance Between Us* 60
5-7 Video Recording of the Performance of *The Distance Between Us* 63
5-8 *The Distance Between Us* Pre-Concert Thematic Expectations 69

6-1 Intervention Musical Interface 77
6-2 Comparison of Participants' Self-Reported Stress and Anxiety 82
6-3 Examples of Control and Intervention Participants' Physiological Data . . . 83
6-4 Intervention Participants' Interface Interactions 84

List of Tables

5.1 Well-Being Workshop Discussion Questions and Participant Responses . . . 45
5.2 *Breathing Together* Audience Survey 48
5.3 In-Concert Well-Being Affect Survey (ICWAS) Questions 55
5.4 *The Distance Between Us* Audience Post-Concert Reflections 70

6.1 Description of the Compositions for the Experimental Musical Intervention 79

A.1 Participant Responses to Question 1 of the *Breathing Together* Survey . . . 114
A.2 Participant Responses to Question 2 of the *Breathing Together* Survey . . . 115
A.3 Participant Responses to Question 3 of the *Breathing Together* Survey . . . 116
A.4 Participant Responses to Question 4 of the *Breathing Together* Survey . . . 117
A.5 Participant Responses to Question 5 of the *Breathing Together* Survey . . . 118
A.6 Participant Responses to Question 6 of the *Breathing Together* Survey . . . 119

D.1 Participant Responses to the *The Distance Between Us* Survey 146

Chapter 1

Introduction

As of 2020, approximately 19% of the adult population in the United States, about 40 million people, had been diagnosed with anxiety disorders, making them the most common mental illnesses in the country. However, only roughly 37% of this population received treatment [5]. Experts estimate that these numbers, which do not include children, undiagnosed adults, and individuals struggling with other illnesses and disorders, have only increased due to the COVID-19 pandemic [130, 137, 142, 157, 170].

Given this current mental health crisis, several intervention methods of anxiety management have been explored, including pharmacological treatments, meditation, and biofeedback [55, 168]. Through this research, music has emerged as a powerful tool for controlling negative affective state. Clinical observations of music therapy have shown that music noticeably helps patients cope with illnesses and disorders, including but not limited to cardiac conditions, depression, Autism Spectrum Disorder (ASD), substance abuse, and Alzheimer's disease [66]. In fact, mentions of the healing power of music in Western society are found as far back as Aristotle's assertion in *De Anima* that flute music could purify the soul, though the first formal discussion of "music therapy" dates to an unsigned article in a 1789 issue of the *Columbian Magazine* titled "Music Physically Considered" [66, 103, 6]. By the 1950s, music therapy became a standardized and accredited field in the United States after the foundation of the National Association for Music Therapy (now the American

Music Therapy Association) and the Certification Board of Music Therapists [6, 83]. However, despite the positive clinical outcomes music therapists observe when using music as a treatment tool, there is still much to be explored in the realm of music-centered anxiety research, with specific regards to effectiveness, efficacy, and interdisciplinarity [66, 52]. In other words, though we know that music typically positively impacts affective state, we do not fully know *how*.

My thesis work approaches this question through the lens of *personalization*, defined in this work as an individual's ability to exert some control over the music that impacts their affect. More specifically, I will explore the space of music-based mental healthcare through both creative and technical lenses, in order to more fully address the optimal ways to leverage music as a tool to promote health and well-being. The work in this thesis serves as the foundation for a much larger body of work, which I will discuss periodically throughout and will elaborate upon specifically during the discussion of future works and directions.

It is most important, however, to establish the importance of music in this mental health space that is already so full of proposed interventions and solutions. Practically, music offers a solution that is (1) portable, (2) scalable, (3) accessible, (4) has proven potential for mood modulation, (5) and is already familiar to the general public [167]. On a more philosophical level, music is the thread that connects searches for meaning, safety, hope, absolution... Music is woven into the fabric of the worst moments of human history, such as Richard Wagner's rampant anti-Semitism that was used as inspiration and justification by Hitler's Nazi party [75] and the sonic torture that occurred in the concentration camps [108]. It is, however, also an integral component of fights for justice and freedom [128, 129], as well as a symbol of hope and connection during the height of collective traumas, such as the COVID-19 lockdowns [111]. The relationship between music and emotion is prominent in popular culture as well, recently portrayed in the Netflix series *Stranger Things*, where Max Mayfield's favorite song (Kate Bush's "Running Up that Hill") saves her and, ultimately, the universe from Vecna's curse [37]. Thus, music is woven tightly into the fabric of society. At its core, it is a reflection of humanity – the best of us and the worst of us. This deep, complex relationship lends itself to further study, with particular emphasis on the impact

of music on our emotions and, therefore, our mental health. The work in this thesis serves as an assessment of this relationship from a variety of perspectives, first with an analysis of the prior research in the field, followed by discussions of the work I have conducted in an effort to further investigate the ties between music and mental health.

Chapter 2

Contributions

The contributions of this thesis are:

1. A method for collecting audience self-report data during concerts and performances that is grounded in the principles of both individualization and flexibility. The discussed strategy provides a method of naturalistic, in-the-moment data collection, as opposed to the traditional retrospective approach, that allows researchers to begin to understand the real-time impact of live experiences on their experimental populations while controlling for hindsight bias.

2. A graphic-based method of musical notation that is grounded in health-related imagery, as well as a strategy for composing with this method.

3. A composition using the technique and notation style discussed in (2), with descriptions of the process and performer reflections, to provide insight into the people and process behind the music that is used to impact listeners' affective states, to work towards gaining a fuller understanding of the ties between music and mental health from all angles.

4. An interface for and implementation of personalized applications of music to modulate physiological and psychological symptoms of anxiety. The work discussed here serves

as a proof of concept experiment with extensive data collection showing initial results, as well as reflections on the lessons, next steps, and applications of this work.

5. Five unique projects in the music for mental health space that collectively provide insight into and work towards demonstrating the importance of creating personalized strategies that work at the intersection of music for intervention and expression.

More generally, however, this work serves as a formative, initial exploration into evaluating and establishing the importance of personalization in music-based mental health and well-being interventions, tools, and activities, as demonstrated by the promising results of the component projects of this thesis.

Chapter 3

Background and Prior Work

This chapter provides a theoretical framework for the original research discussed in this thesis. First, we describe the physiology of anxiety, our chosen case study, to better understand the symptoms that this work aims to alleviate. Next, we delve into the relationship between music and mental health, starting from a macroscopic discussion of creativity and moving, ultimately, to honing in on the relationship between music, physiology, and affect. Finally, we address the well-established relationship between music and health that has existed for generations in cultures across the globe, with a specific focus on the Sinhalese people as a case study.

3.1 Theoretical Definitions

The relationship between music and mental health is widely discussed and debated. As such, it is first important to establish a few key definitions that are central to this work, to promote a standardized understanding of the theoretical backbone. The first and most important is, of course, of **music**. The debate surrounding what music is spans generations, ideologies, and schools of thought. However, for the specific purpose of this work, music is broadly defined as "the science or art of ordering tones or sounds in succession, in combination, and in temporal relationships to produce a composition [oftentimes] having [some

form of] unity and continuity" [101]. While this definition is imperfect, it still provides a framework for future discussions in this thesis. According to the World Health Organization, **mental health** itself is defined as "a state of mental well-being that enables people to cope with the stresses of life, realize their abilities, learn well and work well, and contribute to their community" [121]. However, similarly to music, there is no universal definition of **well-being**, though it is said to include "the presence of positive emotions and moods (e.g., contentment, happiness), the absence of negative emotions (e.g., depression, anxiety), satisfaction with life, [and] fulfillment and positive functioning" [67, 94, 46]. **Mental illnesses**, on the other hand, are defined by the American Psychological Association (APA) to be "health conditions involving changes in emotion, thinking, or behavior (or a combination of these). Mental illnesses can be associated with distress and/or problems functioning in social, work, or family activities" [113]. **Music interventions** to combat mental illness and promote mental health and well-being are defined as:

> [Interventions that have] positive psychological and/or physiological benefits for the participants... [that] neither will have musical developments in terms of increasing technical skills as a primary objective nor will they be primarily concerned with a general increase in artistic activities within the musical domain [91].

Here, **artistic activities** are defined as "the conscious use of skill and creative imagination, especially in the production of aesthetic objects" [99, 1] and **artists** are the individuals that conduct this work, though we must note that the definition of art is also widely contested. These interventions fall under the umbrella of **music therapy**, which is:

> The clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship... [to] address a variety of healthcare and educational goals [including] promot[ing] wellness, manag[ing] stress, alleviat[ing] pain, express[ing] feelings, enhanc[ing] memory, improv[ing] communication, promot[ing] physical rehabilitation, and more [7]

to improve health and well-being. This is, however, not to be confused with general **music listening**, which, in this work, is thought of as a passive form of music consumption, as opposed to active applications of therapy, that also serves entertainment purposes alongside naturally occurring mental health and well-being benefits. In addition, music therapy requires specialized training and formal guidance from a trained music therapist, while music listening is generally less structured and less clinical. Discussions of music therapy and mental health generally center around **affect**, "[a] patient's immediate expression of emotion", and **mood**, "the more sustained emotional makeup of [a] patient's personality" [160]. Finally, as mentioned earlier, the overarching focus and guiding principle of this thesis is **personalization**, which is defined in this work as an individual's ability to exert some control over interventions and experiences meant to impact their own mental health, affect, or well-being. In this musical context, personalization extends beyond merely giving listeners control over the structural elements of music, with emphasis on the promotion of agency via consideration of the prior exposures, preferences, and backgrounds of listeners.

3.2 The Physiology of Anxiety

Before delving further into the relationship between music and mental health, it is important to first understand the physiological origins of Generalized Anxiety Disorder (GAD), the condition that serves as a case study for music-based mental health interventions in this work. According to the National Institute of Mental Health (NIMH), GAD is defined as "persistent feelings of anxiety or dread, which can interfere with daily life [and are] not the same as occasionally worrying about things or experiencing anxiety due to stressful life events" [116]. Common symptoms include restlessness, fatigue, irritability, difficulty concentrating, headaches, muscle aches, stomachaches, unexplained pains, difficulty controlling worry, and issues with sleeping [116]. Anxiety disorders also generally negatively impact both affect and mood [30]. Though the umbrella of anxiety disorders extend beyond GAD to conditions such as Panic Disorder, Social Anxiety Disorder, and Phobia-related disorders (i.e. agoraphobia, separation anxiety, etc.), this work will focus specifically on GAD, referred to hereon out as "anxiety."

The autonomic nervous system (ANS) provides interesting and thorough opportunities to study the physiology of anxiety. The ANS is responsible for controlling unconscious bodily function, including organ and gland activity [78, 82, 112]. More specifically, the ANS plays a major role in regulating rest, relaxation, and the body's fight or flight response, which includes sweat secretion/electrodermal activity (EDA) and heart rate (HR) [78, 82, 112]. Anxiety often manifests as notable change in ANS functions, including increased HR, shortness of breath, "hypersensitivity to adrenergic stimulation", increased interoceptive sensation, and increased sweating [143, 154].

When focusing on internal symptoms, anxiety presents clear patterns of structural activation. The amygdala, which serves as the brain's focus for processing fear-based emotions and memories, is hyperresponsive in patients suffering from anxiety [122, 33, 95]. Anxiety is also tied to activation of the limbic system, which "integrates the sensory, affective, and cognitive components of pain and processes information regarding internal bodily state" [95]. Component structures include the anterior cingulate cortex, the anterior insular cortex, and, importantly, the hippocampus and hypothalamus [63, 43]. The hypothalamus-pituitary-adrenal (HPA) axis serves as the primary endocrine mediator of stress responses, plays a role in stress sensitivity and mood resilience, and is directly involved with the presentation of anxiety disorders [122, 95]. The hippocampus exhibits tonic inhibitory control over hypothalamic stress responses, and the volume of the hippocampus, paired with neurogenesis, is connected to "stress sensitivity and resiliency in relationship to mood and anxiety disorders" [95].

Delving deeper into the microscopic activity that underlies anxiety, prior neurotransmitter-focused work suggests that dysfunction in monoamine neurotransmitter systems, such as the serotonin (5-HT), norepinephrine (NE), and dopamine (DA) systems (known as "neuromodulators"), directly impacts mood regulation [89, 18, 24, 10]. In fact, long-term use of selective serotonin reuptake inhibitors (SSRIs) and serotonin–norepinephrine reuptake inhibitors (SNRIs), which block the reabsorption of serotonin and norepinepherine into the brain, generally reduces symptoms of anxiety, though short-term SSRI use may cause anxiety-like symptoms, such as agitation and jitteriness [89, 18, 24, 10].

This work focuses in part on the use of music to mitigate the macroscopic physiological *symptoms* of anxiety, as opposed to the neurophysiological causes, such as neurotransmitter release and brain activity. In an effort to do so, we measured the activity of the ANS through the collection of EDA, defined as "the variation of the electrical properties of the skin in response to sweat secretion" [12] and heart rate variability (HRV), defined as fluctuations in the amount of time between heartbeats [141], due to the noted relationship between these biometrics and the body's physical manifestations of anxiety [78, 82, 12]. This is not to say, however, that the structural, physiological relationship between music and mental health is unimportant – I will specifically discuss the applications of my work to more neurophysiology-focused studies in later chapters. However, before this, it is first important to gain a deeper understanding of the ways that music and creative practice have specifically been shown to impact both the physiology and psychology of mental health.

3.3 Creativity and Mental Health

Though music serves as a promising and exciting case study for the exploration of novel mental health interventions, it is important to first discuss the general relationship between *creativity* and mental health to understand the overarching principles that underlie this space. There is some debate about the standard definition of creativity [134], including but not limited to "the human capacity to use your imagination to create solutions for complex problems" [97, 80], "the tendency to generate or recognize ideas, alternatives, or possibilities that may be useful in solving problems, communicating with others, and entertaining ourselves and others" [47], "divergent thinking" [38, 159], and new ideas that arise from experimentation [70, 159]. In this work, the definition of creativity is aligned with Walia *et al.*'s dynamic definition, shown in Figure 3-1, which asserts that creativity is "an ongoing act", no matter whether or not it results in the actual creation of ideas, products, or art [159]. More specifically, creativity is defined here as:

> An act arising out of a perception of the environment that acknowledges a certain disequilibrium, resulting in productive activity that challenges patterned

thought processes and norms, and gives rise to something new in the form of a physical object or even a mental or an emotional construct [159].

This definition holds particular relevance to my work, due to the stated origins of creativity – according to Walia *et al.*, creative practice is sparked by "disequilibrium", or the lack of stability, that encourages novel thought and exploration. Though the specific lens for this thesis is music, all of this work is grounded in the idea that creativity allows individuals to come to terms with the world around them, to ultimately build tools to move beyond the difficulties, stresses, and traumas of daily life.

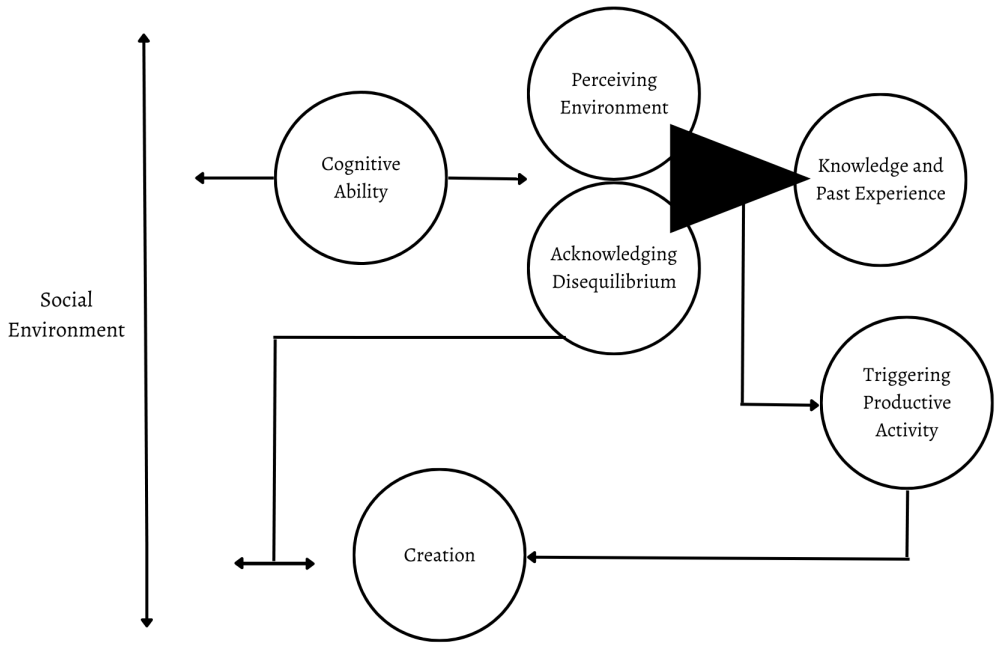


Figure 3-1: Diagram adapted from Chetan Walia's "A Dynamic Definition of Creativity" (2019). The figure above provides a visual representation of Walia's "dynamic definition of creativity", where "an individual's cognition interacts with the social environment, perceives the environment in a certain way, acknowledges disequilibria in the environment (or domain), and interacts with the individuals' past experience and knowledge" [159].

This idea of using disequilibrium to fuel creative change and development is, I believe, the bedrock of the relationship between mental health and creativity. Immersive creative engagement has the potential to encourage therapeutic catharsis and facilitate post-traumatic growth, as seen through the significant role that emotional creativity, specifically defined as "a set of cognitive abilities and personality traits related to the originality of emotional

experience and expression," was shown to play in helping individuals cope with the stresses of living in the COVID-19 pandemic [170, 51]. However, it is also important to keep the complexities of human relationships with creativity in mind when developing interventions. For instance, when surveying professional visual artists, the demands of the work and the industry held high potential for negatively impacting the physical and mental health of the artist, highlighting interesting nuances in the relationship between creation and health that call for more exploration [51]. In addition to this, the context in which one's creative practice originates from and operates in also plays a role in determining emotional impact: when creativity is introduced as an innate, natural tendency, it tends to negatively impact mental health. However, when it is discussed as an intervention strategy or "regular activity," it generally has a positive impact [172].

Though this is only a brief discussion of a subsection of the work delving into the complex relationship between creativity and mental health, these examples highlight the potential for the development of meaningful, impactful interventions and tools to supplement current care strategies. Moreover, it highlights the importance of interventions that are grounded in creative practice, that allow users to experiment and explore without subjecting them to the stress of needing to produce actual output, whether that is a song, a painting, or a dance, that requires any sort of external presentation or validation.

3.4 Characteristics of Anxiety-Reducing Music

The search for the general properties of anxiety-reducing music has been ongoing since at least the 1950s, where "sedative music" was said to require sustained and less percussive "melodic passages", "slow attacks, low dynamic level, simple rhythms," and repetition [49, 161]. This characterization has remained relatively constant: recent work indicates that specific musical factors, like slower tempos (60-100 beats per minute) and simpler rhythms, are often marked as relaxing [45, 39, 14, 44]. Ventilation, blood pressure, and heart rate have been shown to increase with faster tempi and rhythms regardless of genre, while pulse rate and blood pressure reduce while listening to slow-beat music [15, 135]. However, it

is important to note that self-reported perception of the relaxation potential of music is suggested to be highly correlated with listeners' preference, and that definitions of an ideal, reduced-anxiety state differ from person to person [153].

The potential person-to-person variety found in classifications of anxiety-reducing music highlights the limitations of the current standards in the field, though the classical definition of relaxing, sedative music provides a useful and important baseline. Current definitions are susceptible to sample bias based on experimenter music selection in protocols where participants are required to listen to static, predefined pieces. Overemphasizing WEIRD participant populations ("Western, Educated, Industrialized, Rich and Democratic") [62], which we often observe in such studies, may exacerbate this problem by promoting the selection of traditional music from these communities, such as Western classical music. Such strategies may lead to unrealistic assumptions of musical preference uniformity across global populations. My approach provides an intervention that may be useful to a wider population through the introduction of personalization. After all, even though the relationship between *preference* and *relaxation* has been established and discussed widely, there is limited work available interrogating the practical applications of music as an anxiolytic. My approach offers an additional layer of novelty, by assessing the efficacy of interventions that provide users with a locus of control and encourage participation in some manner, as compared to requiring them to passively consume music. The potential impact of the cultural and ethnic/racial composition of sample populations on music preference will be discussed further in chapters pertaining to the limitations and future directions of my work. However, it is important to keep these points in mind when evaluating current widely-used approaches to anxiety-reducing music.

3.5 Music, Physiology, and Mood

As discussed previously, anxiety disorders significantly impact both human physiology and psychology, motivating my focus on both. The neurophysiological effects of music have an established, notable impact. For instance, the combined assessment of [^{11}C]raclopride

positron emission tomography (PET) scanning and psychophysiological measures of the ANS allowed for estimation and identification of striatal dopamine release that was triggered at "peak emotional arousal" while listening to music [136]. Further PET scan-focused work has revealed that reports of pleasurable "chills" while listening to music were marked by increases in HR, electromeyogram (EMG), and respiratory depth (RESP) measures, alongside observed changes in cerebral blood flow in the ventral striatum, midbrain, amygdala, orbitofrontal cortex, and ventral medial prefrontal cortex, which are brain structures thought to be involved in reward, motivation, emotion, and arousal [19]. Interestingly, 77% of participants reported feeling chills when listening to music they had listed as examples that "consistently elicited intensely pleasant responses [for them personally]," while none reported chills during the emotionally neutral control (another participant's chosen music), noise, or silence [19]. Notable differences in structural activation have also been identified when listening to dissonant and consonant sound. More specifically, activity in the right parahippocampal gyrus and precuneus regions of the brain was found to be associated with *increased* dissonance, while activity in the subcallosal cingulate and orbitofrontal and frontal polar cortices is associated with *decreased* dissonance [20]. Moreover, emotional responses to unpleasant music have been shown to activate structures such as the parahippocampal gyrus, amygdala, hippocampus, and temporal pole, all of which are known to be related to aspects of emotion processing, behavior, learning, and memory [54]. Interestingly, in Wesseldijk et al.'s study of twins at the Max Planck Institute for Empirical Aesthetics, it has been shown that, "individuals with higher polygenic scores for major depression (MDD) and bipolar disorder (BPD) were more likely to play music, practice more music, and reach higher levels of general artistic achievements, while a higher genetic propensity for general musicality was marginally associated with a higher risk for a depression diagnosis," even when excluding individuals who exhibited the psychiatric symptoms of MDD and BPD. However, the researchers posit that this relationship is likely due to "horizontal pleiotropy," when one gene influences multiple traits, as opposed to "vertical pleiotropy," which would mean that this observed relationship was due to "causal influences of mental health on music engagement, or vice versa" [164].

In laboratory settings, evaluations of neuroendocrine, autonomic, and cognitive indicators

of human stress showed that baseline values were reached considerably faster in participants who listened to anxiety-reducing music, defined in one instance as "Miserere" by Gregorio Allegri (1582 - 1652), than when at rest without musical stimulation [109, 110, 155, 79, 15]. Exposure to music, both prior to and during stressor scenarios, such as VR-stimulated fear of heights or mock interviews, has been shown to significantly reduce self-reported levels of anxiety [140]. In other studies, participants allowed to listen to music instead of sitting in silence or completing breathing exercises showed the largest overall reduction in blood pressure, HR, and EDA, indicating stress reduction and suggesting the utility of these measures in my own personalization-focused work. Additionally, there is significant evidence supporting the use of music as a non-pharmacological alternative to conventional intravenous anxiolytics in high-stress settings, such as preoperative holding areas (waiting rooms), to reduce self-reported anxiety [56, 77].

Real-world applications of this affect-focused work are highly varied and show notable potential for improving the lives of those suffering from a variety of mental and physical illnesses. For instance, mothers suffering from postnatal depression who participated in group singing for ten weeks reported a plethora of skill-, accomplishment-, emotion-, and community-based benefits [124]. For instance, some mothers stated that they felt a sense of accomplishment in relation to nurturing their babies, "rediscovering a sense of self and purpose," and enhancing the mother-baby bond through learning to sing in these "natural, calming" and non-judgemental groups [124]. Similar promise has been shown through idiographic surveys of males suffering from prostate cancer who sang in the London Tenovus Cancer Choir. Researchers found that choir participation may "provide support in the face of existential uncertainty," "inject some kind of purpose into the week," allow participants to engage deeply with other members, and give the opportunity "let go" and try new things, thus illustrating the benefits of holistic care in the face of life-threatening illness [162]. Moreover, surgical patients instructed to listen to instrumental music two hours before a procedure and during the intra-operative period under light sedation required less propofol and exhibited lower cortisol levels during the procedure, as compared to the group listening to "non-musical placebo [stimuli]" [77].

This concept of holistic care, defined here as comprehensive and personalized methods of treatment that are geared towards supporting the mind, the body, and the emotions together [162] or, more specifically:

> The provision of treatment and care that pays attention to the whole person through the integration of physiological, psychological, sociocultural, developmental, and spiritual dimensions of persons [32, 96]

is used as a guidepost in this work. I argue that, by harnessing the potential of music to provide accessible and personalized interventions and treatments to promote some locus of physiological and psychological control for mental health and well-being, we will be able to achieve significantly improved results when employing music-based care.

3.6 Cultural and Historical Relationships Between Music and Health

Cultures across the world have been using sound and music to boost well-being and healing for generations, from religious to clinical health-focused contexts. The foundational discussions of the functions of music in the 1960s yielded 10 key roles, known as "Merriam's Ten Functions of Music in Society":

1. Emotional expression
2. Aesthetic enjoyment
3. Entertainment
4. Communication
5. Symbolic function
6. Physical response
7. Enforcement of conformity to social norms

8. Validation of social institutions and religious rituals
9. Contribution to the continuity and stability of culture
10. Contribution to the integration of society [98].

This, however, provides several simplifications of the role of music across cultures and societies: music also serves to connect listeners to their personal backgrounds and memories, aid in distraction and diversion, provide a reflection of one's self, and facilitate social bonding and connection [60, 59, 21].

Early modern humans painted their stories and artwork in "acoustic hot spots", or areas of caves where sound reverberated in ways that were conducive to generating echoes [105]. In Ancient Greece, flutes, lyres, *kitharas*, and general vibrations were used to promote healing, from supporting digestion to inducing sleep to improving mental wellness [103]. In the late 1700s, Diogel, a French physician, began investigating the impact of music on physiological responses, such as blood pressure and HR, by bringing live musicians to his patients' bedsides [103]. It is also important to note the religious and spiritual relationship between music and healing that grew alongside, and often superseded, these preliminary scientific explorations. Passages in the Bible mention David using a harp to free King Saul of an evil spirit, with the instruction to "...let us go and look for someone who is good at playing the harp. He can play for you whenever the evil spirit from God bothers you, and you'll feel better" [9, 146]. Recitations of the Qur'an often involve "unconventional melodic vocals" and have been suggested to activate brain regions and elicit therapeutic effects that are comparable to conventional music therapy [73]. The soundscapes of Han Chinese Buddhist temples, which include bells, wind chimes, and chanting, were shown to be significantly correlated with mental health, though the positive effects of such sounds were higher for Buddhist visitors than the general public [171]. In fact, the acoustic characteristics and the "audiovisual congruency" of worship spaces have been shown to amplify emotional impact, though familiarity with the acoustic characteristics and sounds played holds further poignancy [3]. Regardless of the context, these examples of "healing," whether mental or physical, provide a small sample of the countless demonstrated uses of music in health contexts throughout time, region, and religion.

The specifics of this relationship vary from culture to culture. As such, it is difficult to make definitive statements on the role of music in the broad "Eastern" versus "Western" contexts due to the plethora of cultures that fall under each umbrella term. However, one noted difference between the traditions of these groups is the perceived locus of healing: Western definitions of health-centered terms, such as "healing," "cure," and "therapy," generally hone in on alleviating "outer manifestations of sickness," while many traditional Eastern healing practices, such as Indian and Sri Lankan Āyurvēda, are composed of "animistic healing rites and rituals which are designed to treat the root causes of the malady and not their outer manifestations (effected syndromes)" [92].

Sri Lanka presents an interesting case study for this conversation about the diverse practices of music and healing across the world due to the dual presence of both traditional and Western healing practices that began at the outset of colonization in the 16th century and continues into today. This legacy of Portuguese, Dutch, and British colonization has resulted in a notable Western impact on Sri Lankan musical culture as well [163, 71, 144]. For instance, modern *baila* music, which is now generally sung in *Sinhala* (the language of Sri Lanka's Sinhalese majority) and is performed and enjoyed by the Sinhalese diaspora globally, was originally an Afro-Portuguese genre brought to Sri Lanka by Portuguese colonists during their occupation (1505-1685) [144]. In fact, modern Sinhalese pop music is influenced by "Indian film songs, Jamaican reggae, and a myriad of Western musics, including jazz, rock, rap, and hip-hop" [92]. The multifaceted, multicultural ties between music and health in Sri Lankan sub-populations provide illustrative examples of the variety of cultural and historical applications of music across the globe, factors which should be considered when approaching the field of music-centered healthcare today.

3.6.1 Sri Lanka: An Illustrative Example

Though Sri Lanka is a multi-religious, multi-lingual society that is home to a diverse set of ethnic groups, each with their own history and traditions, that include but are not limited to the Tamil, Moor (descendents of Arab and Indian traders), and Burgher (descendants of Dutch and Portuguese colonists that intermarried with local Sri Lankans) populaces, further

discussions of music and health in this chapter will center around the Sinhalese people. As such, for simplicity, I will refer to "Sri Lanka" instead of "predominantly Sinhalese Sri Lankan regions," with the acknowledgement that such musical healing practices are not uniform throughout the nation.

Healing music rituals, which are predominantly employed by the Sinhalese agricultural and indigenous *Veddā* communities, have a general set of uses, defined here as:

> Invok[ing] blessings in instances of individual, community, or national calamities or disasters such as prolonged ill-health, epidemics, floods, etc [92].

Generally, traditional musical performance in Sri Lanka can be divided into two categories: (1) religious, where performance occurs in processions, ceremonies, temples, and specialized *shabda poojas* (sound offerings) and (2) secular, where performance is tied to "life cycles," such as work (including harvesting in paddy fields, fishing, and mining), weddings, and funerals [92]. Traditional Sinhalese rituals, all of which include some musical component, are generally tied to four main sources of power: gods, devils, planetary deities, and ancestors' spirits – for instance, *bali* and *tovil* rituals, which are used to rid participants of *dōsha* (malevolences) and "reestablish psychophysical balance" rely heavily on musical practice [92, 74]. More specifically, these rituals draw upon music, dance, and costume in a way that is reminiscent of the modern psychodramatic approach to emotion processing [17], to provide physical representations of misfortunes and the devils that cause them, to ultimately work through fear, misfortune, and illness via action-based ritual performance [17, 92]. These rituals rely heavily on rhythm, pulling on its potential to "focus energy and bring structure and order," [25] to ultimately provide relief [148, 17, 92]. Even *pirit* (blessings chanted by Buddhist monks) takes on musical qualities:

> They do not sing in unison. Rarely do they hit the same pitch, so that their chanting sometimes gives the impression that they are singing in minor thirds and fourths. Their words are, however, always together and the ornamentation too. In this chanting of *pirit* the *bhikkus* (male Buddhist monks) never go beyond the range of the minor third [150].

Interestingly, however, Thēravāda Buddhist monks are forbidden from both receiving musical education and performing music [88, 92]. As such, despite the musical qualities found in the chanting of *pirit*, its actual musical classification is hotly debated. Regardless of this, there is record of Sinhalese physicians prescribing listening to ritual music and *pirit* chanting to reduce fear and provide relief, since, according to some clinicians:

> There is no medicine to release patients from uncontrollable fears... [A] human being is not a machine to be repaired part by part. The body, mind, and soul are interconnected. Buddhist philosophy suggests the same, and human efforts should keep them in balance. Destruction of this balance results in diseases, which doctors control by prescribing pills. This is not a complete healing and I am against it although I am a Western medical specialist... We can use sounds to create energies and deposit them in our bodies [92].

The relationship between music and well-being in Sri Lanka extends beyond religious contexts as well, and serves the purpose of promoting "(1) personal well-being, (2) [the] welfare of the community, and (3) [the] community's well-being in situations of immediate dangers or intangible continuous troubles" [92]. The *Sokari* and *Kōlam* folk dramas in particular, which involve specific costumes, masks, songs, dances, and criticisms of the societal status quo, allow observers to "releas[e] their tensions through laughing, hooting, shouting, and clapping" in a moment of catharsis [92, 72]. Both performances involve repetitive and rhythmic drum patterns, meant to induce trance states, to allow individuals to "address the problems within [their] own psyche and ward off the fears" [92]. In other words, this collective music-making and performance, characterized by intensive and immersive rhythms, dancing, and singing, is meant to unite community groups, bolster spirits, and provide emotional support and strength, similar to work that we have seen in Western group-performance contexts [124, 162].

Regardless of whether or not one puts weight into this specific relationship between sonic, ritualistic healing and mental health, I believe that this basic discussion of the complexities found in Sinhalese Sri Lankan's relationship with music, health, and well-being provides one

illustrative example of the diverse outlooks that exist in this space. These music-grounded rituals are deeply ingrained into the culture, both in the nation and in the diaspora, and are often completed in conjunction with modern medical practices [163, 71], a relationship that is not standard across other cultures. As such, I assert that when we think of music for health, we cannot assume that all beneficiaries of such interventions will respond to health-focused music in the same way – historical and traditional relationships reveal that each individual culture has its own set of musical rules, traditions, and features for comfort. After all, though Sinhalese participants may find solace in participating in the *bali* and *tovil* rituals, with their elaborate masks representing illnesses and demons and the encouraged screaming, chanting, and singing, such performances may be stress-inducing and, potentially, upsetting for listeners of other cultures.

3.7 Summary

In this section, we have noted several artistic, scientific, and cultural precedents that establish the connections between music and mental health. The work in this thesis will both build upon this existing music and health framework and interrogate some of the intervention and experience design precedents set by the prior literature. More specifically, as previously mentioned, a significant goal of this work is to emphasize the importance creating and deploying personalized music interventions that do not assume unrealistic uniformity in user populations, to provide a sense of agency and control over one's own mental health and well-being.

Chapter 4

Structural Outline

Many neurophysiology-centered approaches assume an inaccurate level of musical uniformity across the global population, which neglects the significance that factors such as musical exposure, training, upbringing, and even trauma have on our music listening preferences. More personalized approaches are standard in classical mental and physical health interventions. For instance, pharmaceutical prescriptions of antidepressants and anxiolytics are usually not one size fits all – for optimally effective care, it is essential to consider the full body composition of the patient. There is prior work in the music therapy space that supports this strategy for anxiety-reducing music: in assessments of the optimal music for affect regulation, participants who were able to actively select their own music experienced a greater reduction in negative affect than participants who listened to experimenter-chosen music [58]. The experimenters did assert, however, that their findings revealed the need for further experimentation to understand the true impact of this strategy for affect regulation. This, I believe, serves as both the motivation and the major contribution of my thesis research. I hypothesize that future music therapy-focused technologies must center around the concept of personalized music listening, to give listeners the agency and flexibility to control what is defined as relaxing, anxiety-reducing, or simply helpful for them, in order to improve their own mental and physical health.

In the process of investigating and assessing this hypothesis, I have divided my work into

a two-pronged approach: (1) music as a form of emotional *expression* and (2) music as a physiological and psychological *intervention*. For the purposes of this work, "expression" is defined as "the process of making known one's thoughts or feelings" [127] and generally encapsulates the interactions with music that occur naturally in daily life, whether that is private listening, concert attendance, performance, or composition. "Intervention," on the other hand, involves trialed and tested applications of music for clinical settings that could be, for example, incorporated into a patient's care plan alongside medication and psychotherapy. It is, however, important to note that "expression" and "intervention" are not discrete, isolated categories. In fact, I believe that the research with the highest potential for positive impact operates at the intersection of these two strategies, where the lines between "expression" and "intervention" blur. For the purpose of thesis organization, however, I will sort projects into one of the two groups, though I will include discussion of the expression-based aspects of my intervention work and vice versa.

The structure of my thesis follows this division: instead of having delineated Methods, Results, and Discussion sections where all of my work is discussed in sum, I will describe each of the five component projects on their own, which will be followed by sections discussing limitations, contributions, conclusions, and future work as a whole. More specifically, in the "Music as Expression" chapter, I will discuss the well-being-centered workshops, personalized audience reaction surveys, and compositions I have worked on in an effort to begin to describe the impact of music consumption and creation on mental health. In the "Music as Intervention" chapter, I will describe my work assessing the efficacy of personalization-centered music intervention for anxiety and stress reduction. Each of these individual projects will include specific descriptions and discussion of their own methods and results. Finally, the "Contributions", "Limitations", "Future Work", and "Conclusion" chapters will bring these projects into deeper conversation, to emphasize the importance of accounting for both scientific and artistic considerations when leveraging music for mental health and well-being.

Chapter 5

Music as Expression

As discussed previously, creative practice, such as singing in a choir [124, 162] or playing an instrument [125], has notable, positive impact on mental health, in part due to its ability to allow performers and listeners to express themselves. There is still, however, much to be explored in this area of research. In my work, I sought to address three separate questions in this space:

(ERQ1) How can we leverage the benefits of musical expression to improve the mental health of at-risk populations?

(ERQ2) How does live music and the opportunities it provides for emotional expression impact the mental health and well-being of audience members?

(ERQ3) How does the act of music as expression impact professional musicians, both as they perform and in their daily lives?

I hypothesized that the general public, regardless of their background, would report that listening to, interacting with, and playing music positively impacted their mental health and well-being, especially when it was framed as something that was created to have such an effect. I also hypothesized that musicians, however, would have a much more complex relationship that would likely be reliant on both whether or not they were performing and the music in question.

In this chapter, I will discuss four projects that were conducted to investigate these research questions. All four studies received protocol exemptions from the MIT Committee on the Use of Humans as Experimental Subjects (COUHES), meaning that each data collection protocol exhibited minimal risk to participants, did not involve the use of drugs or devices, and fell into the exemption category of "Surveys, Interviews, Educational Tests, and Public Observations." The Music and Well-Being Workshop and the *Wellbeing Concerts at Carnegie Hall* were structured to address ERQ1, by providing opportunities for at-risk populations to participate in personalized music-composition-based well-being activities and specifically curated well-being concert experiences respectively. The audience reflection series of projects, including the premieres of *Breathing Together* and *The Distance Between Us*, as well as the *Wellbeing Concert* pilots, addressed ERQ2 by both collecting audience emotion data during performances and working towards optimally personalized methods of doing so. Finally, aspects of the *Wellbeing Concerts*, as well as the surveys conducted during *Breathing Together* and *The Distance Between Us*, were used to address ERQ3, via collected reflection data from the musicians that performed in these concert experiences.

5.1 Music and Well-Being Workshop

On November 17, 2022, the MIT Media Lab's Opera of the Future and Affective Computing groups worked with Friends of the Children Boston (FOCB) to co-host a group of youths (called "Achievers" by FOCB) and adult mentors (called "Friends" by FOCB), shown in Figure 5-1. FOCB is a foundation that works with youth, aged four to eighteen at the time of acceptance, who face multiple systemic obstacles, to provide them with support and professional mentorship for 12+ years following their program start [118]. Six Achievers and four Friends accepted the invitation to participate in a workshop that was designed to expose the Achievers to both music creation and the formal use of music for emotion processing, in an effort to provide participants with tangible, music-centric skills that they could use in their daily lives to impact their own well-being. My role was to co-host and co-organize the workshop with Ila Kumar from the Affective Computing group, as well as to develop and facilitate the workshop activity and collect data throughout the experience.

Figure 5-1: Photos from the workshop co-hosted by the MIT Media Lab's Opera of the Future and Affective Computing groups and Friends of the Children Boston. Invited participants, both youths (called "Achievers" here) and adult mentors (called "Friends" here), were given the prompt, "Please create an instrument that describes a specific feeling or emotion." In order to do so, all Achievers and Friends were invited to create their own MIDI instrument enabled by the Playtronica Playtron®, where found objects, fruits, and vegetables were mapped to sounds found on FreeSound.org, hosted in GarageBand™. All photos are courtesy of Friends of the Children Boston and were anonymized for the privacy of all workshop participants.

5.1.1 Workshop Structure ("Methods")

The workshop participants were invited to the Opera of the Future lab space at the MIT Media Lab. Once they arrived, the Achievers and Friends were given a tour of the lab, followed by demos of current student work, in order to demonstrate what is possible in the field of music technology. Next, the workshop activity was introduced: students were prompted to create their own MIDI instrument that described a specific feeling or emotion. This activity was specifically structured to lean into the ideas of agency and personalization, to give participants a new opportunity to freely describe their emotions in a way that emphasized their own creative self-expression. In an effort to demonstrate how anything can be musical and how present music is in daily life, each instrument was created using three component parts: (1) a Playtronica Playtron® MIDI controller[1], which had sixteen input ports that allowed users to connect up to sixteen objects [126], (2) provided fruits

[1]More information about the Playtronica Playtron® can be found in Playtronica's online documentation: https://shop.playtronica.com/products/playtron

and vegetables, as well as found objects, to connect to the ports, and (3) a computer running GarageBand™ to host audio clips found on Freesound.org that were mapped to the Playtron® inputs. An image of the instrument setup is shown in Figure 5-2.

Participants were given roughly 45 minutes to create their instruments and were invited to perform a piece using their creation at the end of the session. Students from the Opera of the Future group were present to provide technical support and to troubleshoot any issues that arose. One Achiever and one Friend elected to leave before the session had ended. At the conclusion of this allotted time, all of the remaining Achievers elected to perform and present their instruments. Following this, all of the Achievers and Friends responded to discussion questions, shown in the top row of Table 5.1, and then participated in a brief group discussion.

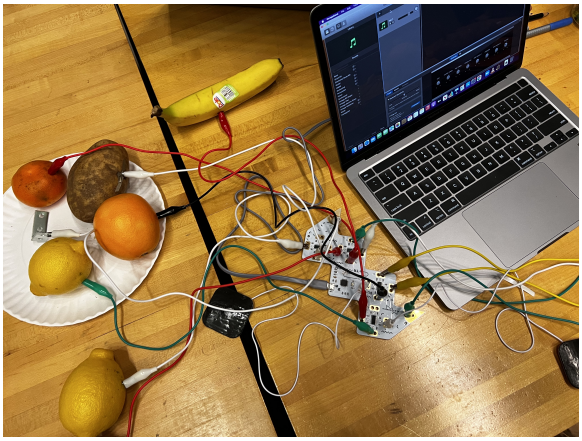


Figure 5-2: Photographic demonstration of the activity setup at the workshop co-hosted by Opera of the Future, Affective Computing, and Friends of the Children Boston. Participants were invited to use found objects and provided fruits and vegetables to build MIDI instruments enabled by the Playtronica Playtron®. They were given the prompt of "Creat[ing] a musical instrument that describe[d] a specific feeling or emotion." Each fruit, vegetable, or object was mapped to a MIDI key in GarageBand™ that held sounds found on Freesound.org. After this activity, participants were invited to share compositions made with their instruments and then complete a reflection exercise and discussion.

5.1.2 Attendee Feedback ("Results")

All attendees wrote their responses to the discussion questions on provided sticky notes that were directly transcribed into Table 5.1. During the discussion at the end of the session, several of the Friends noted that this workshop was "the most engaged the Achievers

Table 5.1: Direct transcription of the responses to the discussion questions collected at the end of the workshop co-hosted by Opera of the Future, Affective Computing, and Friends of the Children Boston. Participants were invited to create a MIDI instrument that described a specific feeling or emotion using the Playtronica Playtron®, where found objects, fruits, and vegetables were mapped to sounds found on FreeSound.org and hosted in GarageBand™.

What is your emotion?	What would you call this instrument?	What does it feel like to **listen** to music	What does it feel like to **make** music?	Does music impact your emotions? Why or why not?
Pensive	Omniphonic	Depends on the music	Fun and challenging	Yes, because they're usually tied to memory...
Somber	A Stefometer	Centering	A little frustrating tbh [to be honest]	Typically improves it. If not, it validates my emotions
Uproar	Fruit Mix	Love it	Feels exciting, mellow	Yeah b/c [because] when I watch TV I cry
My emotion is good	Fruit Mix	It felt good for the first time	Feels good	Sometimes. Depends in [sic.] my mood
(No response)	After party floss fight	It feels amazing to vibe	Was a struggle	Yes it shows how much effort it takes to do so
Relax	The Motion	Kinda soft, kinda beaty	It feels kool [sic.]	Impacts how you feel. And yes
Calm	Tapper	Depending on the music a lot of things. Joy, happy, sad, etc...	It was fun. You had to stay on beat and listen. It was a creative process	Yes, because it's relatable or it can be helpful
Happy	Groovesicle	To live LIFE	To use ur [sic.] emotions as instrument [sic].	Yes, If you listen 2 [sic.] music you'll eventually B [sic.] sad

had been by an activity in a long time," a point that is anecdotally supported via the images included in Figure 5-1. Moreover, one of the Achievers remarked that creating these instruments and composing their own music "remind[ed] [them] about how lucky we all are to be alive." Observations revealed that both the Achievers and the Friends were engaged by this activity, devoting notable care to selecting both the optimal objects to connect to the Playtron® and the sounds/musical fragments that they felt best conveyed their chosen emotion.

5.1.3 Discussion

This workshop suggested the importance of community-centered creation and engagement for the future of music-based health and well-being interventions and served as a real-world example of the potential positive impact that such personalized interventions and activities can have on participants. Though we worked with a smaller population during this workshop, the anecdotal and qualitative data collected shows the promise these composition-based approaches hold as well-being tools and techniques that utilize the power of musical creativity, individuality, and self-expression. Furthermore, this workshop highlighted the importance of working to promote the access of at-risk populations to music-based well-being interventions and strategies, especially those in our community that may not have been exposed to such resources previously. In conversation, all of the participants, both Achievers and Friends, remarked on the use of this workshop for emotional self-expression, which is a key consideration for future work in this space. Notably, this underlines the importance of activities and interventions that are personalized and give agency to users, to help them create their own tools and empower them to express themselves for the benefit of their own health and well-being. This also begs the question of the potential intervention-centered strategies that could arise from such experiences. Potential clinical applications are varied yet significant – for instance, cultivating creative environments that allow for expression and honesty could ultimately lead to more nuanced understandings and relationships between healthcare providers and patients. As such, though some participants found aspects of the workshop exercise frustrating (Table 5.1), I believe this serves as (1) a first

step towards building relationships between the Opera of the Future group and community partners, to use the technology we create to impact our community for the better and (2) a proof of concept of the potential value of personalization and user-control in music-based interventions in general, beyond those piloted in the workshop.

5.2 Audience Response

5.2.1 *Breathing Together*

Figure 5-3: Jessica Shand (soloist, flute) performing in *Breathing Together*, a piece written about the complicated feelings that the global relationship with breathing has come to elicit in the wake of the COVID-19 pandemic. Photo courtesy of Paula Aguilera and Jonathan Williams.

During the world premiere of Professor Tod Machover's *Breathing Together* on October 13th and 14th, 2022, which was part of the multisensory *Brain, Body + Breath* concert written in celebration of the reopening of the MIT Museum, I conducted a series of surveys as a pilot test for assessing the impact of live music on mental health and well-being. Performers and audience members were invited to scan a QR code found in each of their programs that took them to a Qualtrics survey, the questions from which can be found in Table 5.2. This survey was mentioned by Professor Machover when he introduced the piece, though

participants were asked to complete their responses at the conclusion of the show, which occurred approximately 40 minutes after the initial announcement.

Table 5.2: Questions audience members and performers were asked to respond to via Qualtrics survey to assess their perspective on the relationship between music, well-being, and emotion processing through the lens of *Breathing Together*.

Question Number	Question
1	Please indicate whether you performed in *Brain, Body + Breath* or were an audience member.
2	How does music impact your emotion? (i.e. helps with emotion processing, helps you express yourself, etc.)
3	Does attending a live performance increase or decrease your emotional connection to music? If you are a performer, does playing live impact your emotional connection to music?
4	Name an artist whose music you connect to emotionally. Why do you connect with this music? Is there a specific time where the music connects more? Is there a specific song?
5	Please describe your emotional reaction to *Breathing Together*. Were there specific moments you connected to? Were there moments you found too jarring? Did/would knowing the emotions behind the piece help you connect more?
6	Is there music you've heard that you believe best helps you describe or process the emotions that the COVID-19 pandemic has elicited? How/why has that music connected with you the way it has?
7	Is there any additional personal information you'd like to provide about your relationship between music and emotion?

Results We received eight responses to this survey: five audience members, one performer, and two unlabeled. Responses varied in length and detail, and direct transcriptions can be found in Appendix A. Overall, respondents stated that music generally allows them to process and modulate their own emotions, transition between moods, express themselves, and relax. In accordance with requirements of the MIT Committee on the Use of Humans as Experimental Subjects (COUHES) for a protocol exemption, no demographic information was collected. One participant specifically noted that:

> Music has been a part of my identity from the earliest age, and there is a lot about how and why I communicate in the musical world better than with words or actions that I don't understand. But it is something I need and it is a foundation of how I learn about the world.

Four of the eight audience members reported that attending live performances increases their emotional connection to music, while three were a bit more ambiguous, stating that connection can depend on factors such as performance quality and their own engagement. The musician respondent stated that, "At this point, what I play has more of an impact on others than on me. Passively listening is often easier for me to engage emotionally with music." The artists the participants connected with emotionally included Freddie Mercury, Joni Mitchell, Ambrose Akinmusire, OKADA, Aretha Franklin, Aly Halpert, and Johannes Brahms. Specific reasons for selection varied greatly as well, including finding the music "liberating," sharing identities with the artist, detecting specific emotions in the piece, and enjoying the instrumentation. When specifically thinking about emotional reactions to *Breathing Together*, the musician respondent mentioned that they, "Think understanding the story emotionally could help, not always, but possibly. My emotional reactions were enjoyment and pleasure at playing acoustically among ensemble members, where we needed to depend on one another to communicate in order to produce the whole." The audience members generally felt that the flute soloist's playing and stage presence were among the most poignant and impactful components of the performance, remarking that "she was extremely powerful." They also generally reported that knowing the story behind the piece, about COVID-19 and breathing, helped them to connect their own breathing to the music and the ensemble. The responses to the final question, which asked whether participants knew of music that helped describe or process the emotions that the COVID-19 pandemic had elicited, were especially varied. Three audience members and the musician respondent reported some variation of "No." Two participants mentioned using meditation music, with varying levels of confidence, while another stated that music that captured the "numb[ness]" that they felt during lockdown was helpful. Another mentioned that they believed music:

> [Felt] more aligned with the general process of coming to terms with myself and building new neural connections in a changed world rather than with the arc of the pandemic proper (perhaps because those things were happening simultaneously for me as a young adult during quarantine).

The final audience member remarked that music also served as a connection to life pre-

COVID-19, which served as a welcome release.

Discussion Given the small sample size of this study, it is not possible to make generalizable conclusions about the impact of *Breathing Together* on the audiences' emotions and emotion processing. However, the main purpose of this study was to investigate the optimal methods for collecting audience reflections of a musical performance. Though this survey was mentioned before the performances of *Breathing Together*, the audience members and performers were not given time to respond to the questions until after the entire concert had ended. As such, several participants mentioned that they were unable to recall aspects of the emotional impact of the piece, since they were writing their answers with distance from the performance. On top of this, although 33 participants began the questionnaire, only eight completed all of the questions. All of the prompts required relatively extensive written responses which, I hypothesize, contributed to this high attrition rate. Despite this, however, we were able to begin to gather relevant and specific data regarding the impact of music on emotion processing, highlighting the importance of such methods of data collection for future related studies. As such, I propose the following adjustments to affect- or emotion-focused survey tools for concerts:

1. Dedicate time immediately after the performance or piece in question to allow participants to respond to questionnaires. This will ensure that participants are able to recall the details of the experience, and may encourage more audience members to participate.
2. Develop some method for during-concert evaluation of affect, emotion, or well-being. When assessing emotional impact, it is important to understand how audience members felt in the moment as well as after the fact. As such, having some method of data collection deployed during a show that captures the impact of the performance on the listener will be extremely helpful when investigating the full spectrum of emotional impact.
3. Giving participants freedom to express their emotions and reactions is key. Since music listening is an extremely personal experience, reliance upon

standardized measurement tools could lead to participant attrition due to a lack of representation or relevance in the questions, as well as potentially skewed data. By allowing participants to describe their own reactions, feelings, and goals, we will be able to better understand *what* and *how* the music impacted these listeners, providing another example of the importance of personalization in this space.

4. Despite the importance of individuality and personalization, it is also necessary to limit the amount of text participants have to read, as well as the number of required free response prompts. Each of these features can be time- and labor-intensive and also lead to a notable variance in response content and quality. Thus, developing succinct methods of data collection is important for data standardization and participant engagement.

5.2.2 The *Wellbeing Concerts at Carnegie Hall*

The *Wellbeing Concerts at Carnegie Hall* are a collaboration conducted among the Carnegie Hall Weill Music Institute, Enact:Lab, the University of Copenhagen, and the MIT Media Lab. In this series, which runs from March to June 2023, teams of musicians and hosts are invited to create an immersive musical experience (Fig. 5-4) to promote the emotional well-being of one of our two target groups, either individuals impacted by the justice system (Group J) or New York City healthcare workers, their families, and their friends (Group H). Sarah Elizabeth Charles and Jarrett Cherner performed March 5, 2023 (Group J) and Emeline Michel and her band on April 16, 2023 (Group H). Two additional performances, each with a new set of musicians and hosts, will run on May 23, 2023 (Group J) and June 18, 2023 (Group H).

Though the central goal of this series was to provide populations at-risk for mental health disorders with an afternoon of relaxation and reprieve, these concerts also served as a pilot study targeted at understanding the impact of live music on well-being, with an ultimate goal of providing Carnegie Hall with strategies that they could deploy in their regular season programming. This "well-being impact" is defined as:

1. *New Benefits:* Offering a soul-nourishing new way of benefitting from music
2. *Shared Experience:* Offering a collective creative experience that builds community through the shared experience of silence and sound
3. *Practices to Take Home:* Giving audience members practices that they can take home with them after the experience
4. *Self-Care Messaging:* Supporting specific self-care messaging

in order to "better understand the elements of the experience that deepen the positive impact on listeners' sense of well-being before, during, and after attending a musical performance[2] [106]." Thus, the guiding principles of this project are to (1) identify elements of a concert that contribute to meaningful impacts on well-being that extend beyond the time spent at the performance, (2) identify ways to develop and amplify elements of concerts that improve well-being, (3) explore whether the well-being principles that underlie a well-being-focused concert can be applied more broadly to other types of concerts, and (4) assess what we can learn about the benefits of "thoughtfully designed, research-responsive live musical performance for individual and collective well-being through the program[3] [106]"

Project Design Data collection can be divided into three main categories: pre- and post-concert interviews and during-concert well-being evaluation. Though this series is a collaborative effort among all of the involved institutions, each group was assigned specific action items to ensure the success of the pilot. Kristian Moltke Martiny (Enact:Lab), Morten Kristensen (Enact:Lab), and Elīna Bresle (Enact:Lab, University of Copenhagen, Arbejdsfællesskabet PB43) designed and carried out the pre- and post-interviews targeted at investigating participants' relationship with music, live performance, and well-being, and also provided feedback on the during-concert data collection strategies. Ian Koebner (Carnegie Hall, Harvard University) and Manuel Bagorro (Carnegie Hall, Music Connections Program) provided detailed feedback throughout the design process and were responsible for recruiting participants for the pre- and post-concert interviews, as well as coordinating

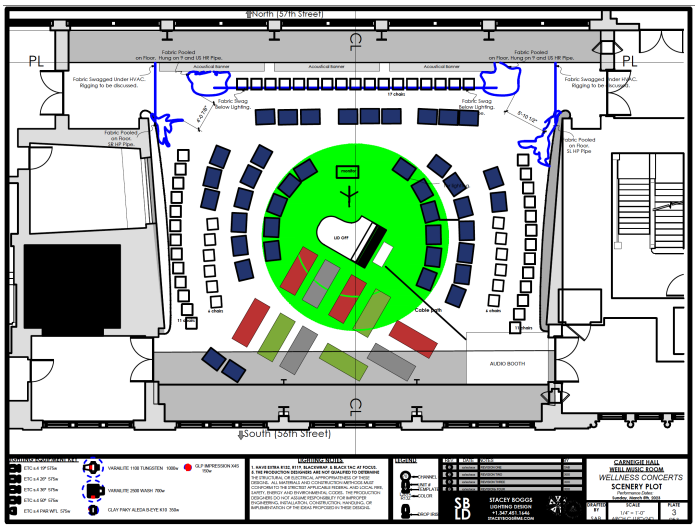
[2]The definition and goal of "well-being impact," as well as the overall goals of the project, are from the internal research design document written by Kristian Moltke Martiny.

[3]*Ibid.*

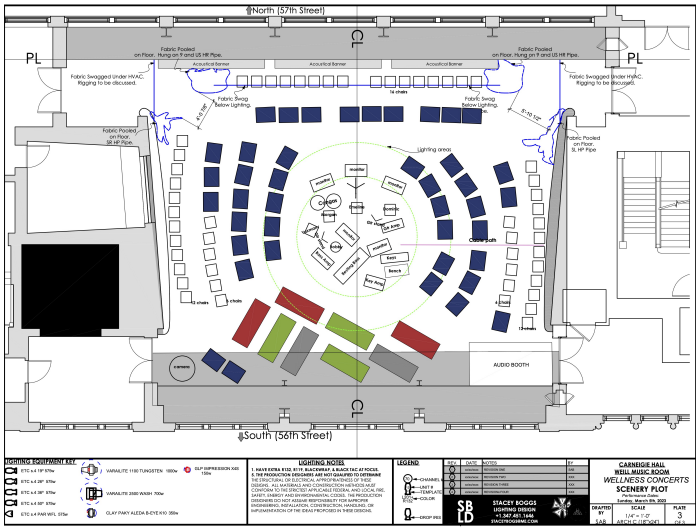
the performance space and the performers. My role was to design and deploy a system to evaluate well-being during the performance without disrupting the atmosphere, to analyze the resulting data, and to help iterate on the interview questions. This during-concert survey provides a novel method of well-being assessment during concert and performance experiences.

The Importance of During-Concert Data Collection The standard in the field is to collect either questionnaire or interview data before and after an experience, to understand the way participants' thoughts, feelings, or perceptions have shifted. We, however, believe that there is a plethora of vitally important and useful data to be collected *during* performances that may be lost in the time it takes to respond to retrospective surveys or meet with interviewers. There is prior evidence supporting the importance of continuous measurement during performance – for instance, Waddell and Williamon demonstrated that the presence small, specific visual events that audience members may not recall retrospectively, such as "inappropriate stage entrance," can negatively impact "evaluative and aesthetic judgments in musical contexts." While paired audiovisual stimuli, such as "aural errors [paired with] frustrated facial expressions," generally led to *persistent* decreases in perceived quality, solely visual cues often only led to *temporary* decreases, highlighting the importance of collecting some form of continuous data to get a full understanding of audience experience [158]. This approach was in part inspired by what I learned through the *Breathing Together* surveys, where participants remarked that they were responding long after the concert had ended and had forgotten some details and emotions that were impactful in the moment (Appendix A).

Survey Design Process The overall performance structure of this pilot series is complex: stage and lighting design, audience activity, genre, and performance style are all independently determined by each host and musician team. As such, there are very few, if any, constant variables between each of the concerts. In order to measure well-being consistently during each of these experiences, we required a strategy that would allow us to collect both flexible and meaningful data. Here, we elected to lean into the idea of personalized data



(a) March 5, 2023, featuring Sarah Elizabeth Charles (vocals), Jarrett Cherner (piano), and Matthew Steinfeld (host).



(b) April 16, 2023, featuring Emeline Michel and her band, with Yazmany Arboleda (host).

Figure 5-4: **5-4a:** Stage design of the March 5, 2023 *Wellbeing Concert at Carnegie Hall*. The hosts and performers sat at the center of the green circle, around the piano. **5-4b:** Stage design of the April 16, 2023 *Wellbeing Concert at Carnegie Hall*. The host and performers sat in the inner circle, inside the green dotted lines. In both performances, audience members were invited to sit on chairs and cushions, or to lay on mats that were all arranged in semi-circles surrounding the stage. Images courtesy of Stacey Boggs and Carnegie Hall.

collection, similar to what has been seen and validated in measures such as the Measure Yourself Medical Outcome Profile® (MYMOP), which is used to ensure "individualized assessment of patient-centered outcomes" in clinical healthcare settings [68, 123].

As such, while they waited for the performance to start, audience members were asked to report how they hoped the concert would help them reach a specific well-being goal (Appendix B.1.1). We then populated a seven-point Likert scale [114] with this response, and, at the middle and end asked of the performance, asked audience members to rate how successful the concert was in helping them achieve their previously stated well-being goal (Appendix B.1.3 and B.1.5). We also believe such strategies reduce the presence of experimenter bias in our pre-, during-, and post-concert data collection, since we are not limiting participants to our definitions of what well-being is. A list of questions from the April 16, 2023 pilot of our survey, called the In-Concert Well-Being and Affect Survey (ICWAS), can be found in Table 5.3.

Table 5.3: Questions included in the April 16, 2023 pilot of the *Wellbeing Concerts at Carnegie Hall* In-Concert Well-Being and Affect Survey (ICWAS).

Question Number	Question
1	We know that people think about well-being in many different ways. Please take a moment to think about what well-being means for you. With this personal understanding of well-being in mind, how do you hope this concert impacts your well-being?
2	Thank you for taking a moment during the concert to reflect on your experience. Earlier, you told us that you hoped this concert would impact your well-being by [response from Question 1]. How successful has the concert been so far in helping you towards this goal, from 1 (not helpful at all) to 7 (completely helpful)?
3	Thank you for attending the show. Earlier, you told us that you hoped this concert would impact your well-being by [response from Question 1]. Now that the concert is over, how successful was the concert been in helping you towards this goal, from 1 (not helpful at all) to 7 (completely helpful)?
4	Thank you for reflecting with us. We're so grateful for your presence and your time. If you are willing, we would love to hear any reflections or feedback you have from today's performance. Feel free to either upload a video/audio clip or provide a written response.

ICWAS: A During-Concert Well-Being Survey We piloted an initial ICWAS during the March 5, 2023 *Wellbeing Concert* on a small sample of pre-selected attendees (Fig. 5-5). Through this experience, we identified a series of necessary improvements to the protocol, including the need to allow participants to upload audio, video, or written responses regarding their experience before the conclusion of the survey, as well as the importance of interviewing the performers and hosts about their own experiences, both related to well-being and the general performance. The delivery methods of this during-concert survey

were also called into question during these revisions. During the first concert, both the musicians and the research team noticed that audience members almost immediately pulled out their cellphones to take photos, record videos, and browse the Internet. We sought to limit electronics usage in future concerts, to encourage audience members to immerse themselves in the performance and gain as many well-being benefits as possible. The ICWAS, however, was hosted on Qualtrics and was, thus, completed on participants' cellphones. This raised a series of concerns regarding the impact of cellphone usage on the concert experience, especially since device usage could yield reductions in audience immersion, engagement, and focus that could negatively impact both the overall experience and our data. We sought to account for this complication by requesting that each host build specific references to the ICWAS into their script, to cue audience members to take out and put away their phones at specific points during the performance. This also served to integrate the research protocol further into the concert experience, to create a more immersive atmosphere. Finally, the musicians, hosts, and research team agreed that it is vitally important to provide audience members with an emotional scaffolding as they leave the venue, whether that is access to mental health and well-being resources or guided imagery recordings to allow them to step through the concert experience again whenever necessary. This final improvement provides a further example of the interesting synergies that exist at the intersection of "expression" and "intervention." The *Wellbeing Concerts* were created to serve as a venue for audience members to connect with the music and the performers, in the hopes that this would allow them to express themselves and process their emotions. In doing so, we have identified new, useful methods of potential intervention derived from this initial expression-centered experience that we may not have identified otherwise.

Data from the revamped pilot of the ICWAS on April 16, 2023 showed that there was no significant difference in the success of the concert during and after the performance in bringing the audience closer to their chosen well-being goals (paired t-test, $t(11) = -1.39$, $p = 0.19$). However, all participants generally reported that the experience was positive, thus providing a preliminary demonstration of the self-reported well-being benefits of the experience. Once we have a larger sample population, we will conduct within- and between-subject data analyses, in an effort to investigate the role this experience plays in well-being

Figure 5-5: Photos from *the Wellbeing Concert at Carnegie Hall* held on March 5, 2023 that display the performance setup in action. All photos are courtesy of Carnegie Hall and were anonymized for the privacy of all audience members.

improvement. However, in order to fully assess the impact of these concert experiences, it is important to first understand the audience members' *initial* states, to be able to compare these baseline results to the during- and after-concert measurements. Beyond this, we plan to pilot a revised, hard copy version of the ICWAS during the May 2023 concert, to compare subjective audience experiences and completion rates between the physical and digital survey methods (Appendix B, Sections B.2.1, B.2.2, and B.2.3). The specific results from this pilot have been withheld at the request of my collaborators in the interest of future work.

Audience and Artist Reactions Audience responses to the performances themselves have been glowing, with feedback ranging from "I feel alive and loved", to "It's amazing

that something as peaceful as this exists in this city", to "It's rare to take a moment to turn off my mind", to "It's a surreal and nebulous feeling, like we're on a cloud together – this is a safe zone and I'm thankful for it." One participant even mentioned finding it difficult to return to "Gotham city" after such a "beautiful, safe experience."

The musicians and hosts reported similar levels of impact. One remarked that:

> I felt altered, in a very cool way and in a very new way. [Performing] and telling stories [oftentimes] comes with making eye contact with the audience and other things that felt very different in this context... Instead of performing, I was trying to participate as much as possible in what was happening, and that was both for myself as a selfish choice and also a choice that felt appropriate in relation to what we were inviting everyone else to do and what we were trying to cultivate... I was really trying to leave [performing] at the door, because I was afraid of impacting and influencing other peoples' experiences too much. I wanted the sound to guide the experience, not the visual aspects [of body movement, facial expression, etc.].

Another musician noted that, while they felt that the performance experience was not overtly out of the ordinary for them, they found themselves narrowing the dynamic bandwidth of their playing in an effort to keep the audience's focus on the well-being experience and not on the musicians' musical prowess, though this shift may not have been perceptible to anyone else. The hosts have noted the applications of this series for clinical practice as well, for helping to emotionally settle patients in crisis. Both the musicians and the hosts also commented on the impact of interacting with audience members before and after the show on their experience, especially since it is generally uncommon to connect with audiences in such a way during standard concerts.

Discussion The ICWAS was designed to address the data collection deficiencies identified through the *Breathing Together* survey, thus yielding a novel method of data collection during performances that is personalized to each audience member. Specifically, we (1)

built structure into the concert programming for participants to take this survey by asking the host to allocate time 30 minutes into and at the end of the performance for survey completion; (2) developed a personalized method of during-concert evaluation of well-being that gave participants freedom and control over their experience by allowing them to choose what affect, goal, or aspect of well-being they monitored over the course of the concert; and (3) eliminated reliance on long-form free response questions and instead elected to use personalized Likert scales to collect self-reflection data. Initial audience, musician, and host reflections on these concerts highlight the importance and impact of this work: by creating spaces that explicitly link art and well-being, people are empowered to connect with their emotions and experiences in ways that open them up to creative points of catharsis and relief, thus encouraging further thinking about mental health, well-being, and therapeutic care. Though our initial survey pilot did not yield significant results, it did highlight the positive impact of the *Wellbeing Concert* experience as a whole, as well as the potential benefits of the personalized nature of the ICWAS, while demonstrating deficiencies in the existing survey structure that will be corrected in anticipation of the May 2023 concert.

However, it is important to note that this series of projects is ongoing, and a true analysis of results from the ICWAS will only be possible at the end of June 2023, once the last of the pilot concerts has occurred. Regardless, this phase of the project serves as an opportunity to identify the optimal methods of during-concert data collection. In fact, this iteration of the *Wellbeing Concerts* serves as a pilot study for the pre- and post-study interviews as well, since we hope to roll out an improved research protocol grounded in what we have learned from this four concert series in the Fall of 2023.

5.2.3 *The Distance Between Us*

The Distance Between Us, for augmented duo, is a piece I composed as a meditation on the early pandemic, where "normal life" was turned on its side seemingly overnight. The piece is inspired by the impact of COVID-19 on human physiology, is rhythmically informed by the soundscape of the intensive care unit (ICU), including pulse oximeters, ventilators, and heart rate monitors, and is thematically shaped by the first-hand accounts of healthcare

Figure 5-6: Charlie Lovell-Jones (violin) and Jessica Shand (flute) performing during the world premier of *The Distance Between Us* (Fig. 5-7), a piece written using the soundscape of the intensive care unit (ICU) to evoke the complex feelings and emotions associated with the early days of the COVID-19 pandemic and the beginning of the first lockdown. Photo courtesy of Jimmy Day.

workers on the front lines. The piece is divided into three sections. At the beginning, the musicians — in this performance, a flutist and violinist — are asked to follow a more rigid structure, emulating these physiological measurements at a steady state, though this consistency rapidly degrades with time. At the conclusion of this section, the musicians were instructed to rapidly shift into the alert tones of these monitoring devices to convey a sense of panicked urgency. In the middle, they are encouraged to explore and improvise, to tell their own story of their experiences of the pandemic in the framework of the piece. At the end, they are asked to come back together in tentative starts and stops, to try to fit back together as they once did (Appendix C).

On April 3, 2023, Jessica Shand (flute) and Charlie Lovell-Jones (violin) performed *The Distance Between Us* at the MIT Media Lab as a part of the "Arts Around the Lab" event displaying student work (Fig. 5-6; Fig. 5-7). This performance serves as both an idiographic study of the use of music composition and performance for emotion processing and a case study of audience responses to music written about emotionally fraught subject matter. The following chapter is structured differently from the rest of this thesis: while I have still conducted analyses of data gathered from the audience, I have also included composer and

performer reflections, in an effort to provide insight into the people and process behind the music that is used to impact listeners' emotional states, to gain fuller understanding of the ties between music and mental health from all angles.

Reflection on Composition Process and Performance At the beginning of the composition process, I knew that I wanted to write a piece that was grounded in physiology, as is the nature of the majority of my current music-centered work. This, I felt, was doubly important in light of my subject matter: I found it difficult to think of the impact of the COVID-19 pandemic without paying tribute to the intense biological and societal losses and costs we have faced over the past three years. Moreover, after spending the lockdown watching my father, a critical care anesthesiologist, live through the chaos of working in the ICU, I knew that I wanted to tell at least a small part of the story of the intensity of caring for those severely impacted by COVID-19. With this in mind, I decided to use the sounds of pulse oximeters, ventilators, and heart rate monitors as motifs in the composition, all of which were used to monitor and support COVID-19 patients in the ICU.

The next major question in this process was that of notation. Though the standard Western classical notation on five-line staves allows for expressivity and experimentation in its own right, I was instead inspired by the freedom and room for interpretation afforded by graphic scores. Drawing inspiration from Nicole L'Huillier [86, 87], Jeanne Bamberger [11], Pauline Oliveros [120], Nicole Mitchell [104], Dai Fujikura [48], and George Lewis [85], I wanted the score itself to serve as an artform, to tell a story in parallel to the music. As such, I developed a notation style that referenced the biometric motifs, to ground the music in and allow the musicians to further connect with this health-centric context. In pursuit of this, I drew inspiration from heart rate monitor and pulse oximeter waveform visualizations, and used their graphic structures to denote dynamic changes in the piece (Appendix C).

Though *The Distance Between Us* was written as a reflection of my own perspective and thoughts on the pandemic, I wanted to give the musicians the freedom to tell their own story. As such, during the middle section of the piece, which was cued by the shift from the steady state sounds of the pulse oximeter, heart rate monitor, and ventilator to the alarm

rhythms, the performers were given the freedom to improvise within a skeleton framework. This, of course, brought about questions regarding their musical and narrative relationship. I purposefully wrote the score in a way that opened this up to interpretation, which would, in turn, dramatically impact the emotions expressed in the piece from duo to duo and performance to performance. For instance, the musicians could choose to portray a conversation between a physician and a COVID-19 denier, a COVID-19 patient and a family member, a physician and a family member, two individuals from two separate countries discussing their experiences, a COVID-19 patient and their monitoring system... As such, during our five-hour-long rehearsal the day before the premiere, I worked with Jessica and Charlie to pinpoint which relationship they felt was most representative of the emotions they chose to express. Ultimately, we decided that Jessica would play the part of the ventilator and, thus, the patient and that Charlie would represent the physiological monitoring systems.

This conversation, I believe, was essential to bringing *The Distance Between Us* to life in more ways than one – the honesty and vulnerability of these discussions exemplified the purpose of this piece, to give individuals with different backgrounds and perspectives the flexibility to come together and lean in to the therapeutic nature of music, to tell their own story and process their own emotions. This is also why I elected to use a graphic score: at the end of the day, every individual's experience during the pandemic was unique. It was not my place to dictate how Jessica and Charlie described their own experience, and I found it important to emphasize that, though I am the composer, this was ultimately not about me. In this specific iteration, *The Distance Between Us* became Jessica's and Charlie's, to allow them to express their own thoughts, experiences, and ideas within the framework I created. No one will be able to play their version of *The Distance Between Us* in the exact way that they did on April 3rd, and I believe that this in itself contributes to the meaning and value of the performance. They told their story from their perspective at that moment and, if they perform this together again, the piece will give them the freedom to express how they have grown and their perspectives have changed in the interim.

Jessica's and Charlie's relationship in the piece was expressed through their movement as well as their musical performance. At the beginning of the piece, while they played the

Figure 5-7: Link to the video recording of the premiere of *The Distance Between Us* in the MIT Media Lab's Dreyfoos Lecture Hall. Video recording by Jimmy Day, audio recording by Max Addae.

steady state monitoring sounds, Jessica stood in front of Charlie as he observed her intently, as a representation of a patient in a hospital bed. Over the course of the first movement, once they began introducing the slight variations in the musical baseline, Jessica and Charlie began moving away from each other without making eye contact, towards opposite ends of the stage. Once they began playing the alert tones at the beginning of the second movement, however, they maintained extended, almost adversarial eye contact as they moved into the intense improvisation. The musicians were provided with specific sonic tasks during the second movement, which included call and response and an improvised canon. The tempo and duration of these tasks were left to the discretion of the performers, in an effort to contribute additional visual and musical intensity to the crescendo leading into the point of release that signified the start of the third and final movement. This last movement began with an audible inhale from both musicians as they ceased playing, followed by a series of heavy breaths in the silent room. Note by note, literally and metaphorically, Jessica and Charlie began building back towards the melodic baseline established in the first movement, without ever reaching a full return to "normalcy." Visually, they slowly walked across the stage, towards each other, to ultimately end the performance playing back to back. This sudden silence after the intensity of the second movement, followed by the hesitant near-return to the motifs of the first movement, was written to feel unsettling yet cathartic for both the performers and the audience (Fig. 5-7).

Though one of the goals of this piece and performance was to provide the audience members

with a space to reflect on their experiences over the course of the pandemic, I had assumed that, for me, the majority of emotion release and processing would occur while composing. In reality, however, I found the rehearsals and performance to be the most emotionally valuable, largely due to the care and feeling that Jessica and Charlie channelled into their performance. Our discussions about the piece in particular were cathartic – as we collaboratively decided on the story they would convey, as well as the rough sketches of their improvisations, we were all encouraged to discuss our pandemic experiences, fear, worry, and sadness. Seeing and hearing these conversations take on a life of their own during the premiere was more rewarding and poignant than I initially anticipated. Being able to see my story, as well as the stories of my friends, reflected on stage held significant value that I believe exemplifies the importance of personalization in music for affect, whether that is through encouraging composition and creation as a method of emotion processing or by allowing listeners to use the music they personally connect with to modulate their own emotional state.

Survey Structure We were informed by the logistical findings from the *Breathing Together* and the *Wellbeing Concerts at Carnegie Hall* pilots when determining the best method for surveying the audience. Since this performance was of a single, 15-minute piece and not an entire concert, we elected to remove the during-performance measurement component to avoid disruption for the audience. This, however, meant that the Likert component of the ICWAS was no longer feasible since, in this instance, we did not have an initial set of ratings to compare to the post-concert results. Thus, we found that free response questions were necessary. This does not mean, however, that we decided against using all elements of the ICWAS. First, before the performance began, audience members were asked to respond to a preliminary intention-setting, pre-concert question (ISQ):

> We know that the relationship between music, well-being, and emotion processing differs greatly from person to person. Please take a moment to think about what this relationship means to you. With this in mind, what do you believe the emotional effect of a musical composition written about COVID-19 should

be?

Keeping the lessons from *Breathing Together* in mind, at the end of the performance, participants were asked to complete a single, reflective open response question (ROQ) immediately after the performance concluded:

> At the beginning, you mentioned that the emotional effect of a musical composition written about COVID-19 should be: [Answer from Question 1]. Please reflect on your experience at this performance. What would you change to bring you closer to this goal? What would you keep the same?

Through this, we hoped to gain an understanding of the audience's reactions to the piece immediately following its conclusion. We decided against explicitly asking participants to comment on the success or failure of the piece in order to avoid leading questions and to encourage the audience to provide honest, unfiltered feedback, which we knew from our prior work would likely involve such discussions regardless. By asking participants to reflect on the emotions and ideas they provided before the performance, we hoped to encourage them to dive deeper into discussions of the emotions they detected during the piece, in the hopes that this personalized method of data collection would encourage further internal reflection about their own pandemic thoughts, feelings, and experiences. Additionally, we wanted to encourage participants to provide as much detail about their experiences as possible, and were concerned that some would see success-and-failure-centric phrasing as an invitation for a yes-or-no response. As such, we emphasize the idiographic nature of this evaluation: though our results center around a specific piece and performance, we believe they serve as a first step towards future work with musicians targeted at gaining deeper understandings of audience reactions to and relationships with their music, as well as an assessment of ways to incorporate open response questions into surveys like the ICWAS. This strategy also serves as a point of comparison for prior open-response strategies: the *Breathing Together* survey centered around intensive, open-ended questions that were reminiscent of what could be found in a laboratory setting, while the *The Distance Between Us* survey was focused on gathering pre- and post-experience data in a way that encouraged organic audience

response and interaction. In future studies, we plan to gather more *experiential* data through questions that specifically focus on how the experience made participants feel in addition to our current, more goal-oriented structure.

Musician Reflections In a publicly shared reflection on *The Distance Between Us*, Jessica Shand (flute) wrote the following:

> Getting to work on *The Distance Between Us* with Kimy, a close friend and colleague, and Charlie, whom I hadn't met prior to the context of this work, was such a treat.
>
> Over the weeks leading up to the premiere, I got to see the notation for the piece solidify into something that is both technologically grounded and emotionally evocative. The red and blue spikes and dips (as one might read on a patient monitor) and the transcriptions of sounds (such as a ventilator) that one would hear in the ICU at the height of COVID-19 automatically set me up, as an interpreter of the score, to contemplate that episode in our shared history. Whereas classical Western notation often creates some distance between the performer and any relevant representational content in the music, with the latter only to be speculated upon decades or centuries later, this is not the case for *The Distance Between Us*. This score does not shy away from its dealings with the on-the-ground realities of the pandemic and the associated grief. At the same time, Kimy gives the performers ample room to interpret all of it as they will; as discussed in rehearsal and made clear in the text at the top of the score, she really wanted us to have the opportunity to say what we wanted to, if we wanted to, through improvisation. This felt especially important and sensitive given the difficult subject material, and barely scrapes the surface of the compassion and care that Kimy showed to us as performers touching on potentially traumatic memories (and that, frankly, all composers should aspire to).
>
> In rehearsal, I found myself indeed reflecting and remembering. It was cathartic. As an instrumentalist, what I communicate musically I communicate without

words, and I love that [this] can take an audience on a whole journey without clueing them in to the specifics of what I've been through. There's this veil, this level of privacy that I can make as robust as I want. But actually, what really struck me about this piece as a performer—beyond the opportunity to reflect or to remember—was the opportunity to deeply connect with another musician on a human level, in a way that not all scores afford to their performers, and in a way that the pandemic made impossible for quite some time.

Because Charlie and I chose not to use any external, fixed measure of time, such as a clock, a metronome, or a click track, the entire contour of the piece depended on our having a deep and shared understanding of the relationship between the two parts. More than that, the piece required us to be present and attentive of one another on an affective level, since the music moves according to deviations from a baseline that is removed and rigid but also calm and cool. In other words, our ability to keep time in performance—to mutually sense where we were in the score, the most basic aspect of playing any more-than-solo repertoire—demanded that we tune in to minute affective changes in one another's playing. This included changes not just in sound, but also in comportment, the way we held ourselves physically.

In having this marathon rehearsal with Charlie and Kimy and then giving the world premiere of the piece the following day, I feel I was gifted with the chance to do the thing I love the most, which was also one of the things that the pandemic made impossible. It's intimate musical collaborations like this that make me feel the most connected, the most human. Like everyone else, I have layers of memories from the COVID-19 pandemic, tinged with fear, uncertainty, anxiety, and dread, but also moments of relief, freedom, and happiness. The time that Kimy set aside for us in this piece to reflect on all of those memories implicitly forged a new layer, a new memory, and I'm reminded of something the composer Tyshawn Sorey said in a recent lecture: "nothing ever really finishes, and everything has an afterlife." If that afterlife brings with it some newfound community, I'm game.

Though Jessica's thoughts reflect her individual experience, they make a compelling case for the value that music may hold for emotion processing and catharsis for even the most experienced musicians, especially when bending and stretching traditional musical structures.

Audience Reactions All of the 21 people who began the audience survey completed their responses, though one respondent's ISQ and another's ROQ responses were removed as they either did not respond to the provided question or their responses were unintelligible. Audience members generally responded positively to the overall structure, with one participant even commenting that:

> When I saw the QR code I thought "Oh no," but I really liked the opportunity to reflect on what I said at the beginning at the end, and I liked that there weren't a lot of questions to respond to.

This moment of reflection validates the grounding principle of the ICWAS, as well as this work's focus on personalized strategies of both assessment and intervention for music-centered research. This point is further emphasized by the quality, detail, and length of the responses collected as compared to the *Breathing Together* survey.

Each of the respondents' ISQ answers were analyzed and coded to assess the positive (i.e. hope/healing/peace or catharsis/resolution), neutral (i.e. connection/communication or emotional release/processing), and negative (i.e. grief/sadness/suffering/loss or anxiety/fear/panic/darkness) themes present. Using this system, seven negative, seven neutral, and six positive subthemes were identified. However, it is important to note that fifteen of the twenty responses mentioned some form of an emotional ark, whether that included all three themes or some shift from negative to neutral or positive (Appendix D). More specifically, four responses solely mentioned positive themes, one solely neutral, four negative and positive, three negative and neutral, four positive and neutral, and four a combination of all three themes. Healing/peace/hope was the most common expected subtheme, closely followed by sadness/suffering/grief/loss (Fig. 5-8). Interestingly, some

Figure 5-8: Audience ideas of what emotions a composition about COVID-19 should elicit, in response to the prompt: "We know that the relationship between music, well-being, and emotion processing differs greatly from person to person. Please take a moment to think about what this relationship means to you. With this in mind, what do you believe the emotional effect of a musical composition written about COVID-19 should be?" Blue circles represent negative themes, green neutral, and yellow positive. The number below each subthematic label signifies the number of participants that referenced each subtheme in their response.

subthemes, such as community, were discussed with both positive and negative framings: participants mentioned wanting to recall the development of new connections and the time spent with loved ones while others mentioned community losses and sacrifices. Overall, the pre-concert responses demonstrate the variety of expectations that audience members brought to the performance, both in comparison to other individuals and within their own ideas of what a piece about COVID-19 should represent.

Eighteen of the twenty ROQ responses were explicitly positive, with two specifically mentioning that the emotions of the piece matched the emotions they mentioned in their ISQ responses. The two remaining responses were neutral and provided constructive feedback (Appendix D). Nine participants provided specific examples of musical and performance

Table 5.4: Specific audience post-concert reflections that discuss the emotions they identified in *The Distance Between Us* and the features that caused them.

Participant	Emotion/Subtheme	Musical/Performance Feature that Created This
1	Chaotic and uneasy with a sense of relief at the end	(1) Sounds, rhythms, and pitches "coming from different times and places"; (2) performers' energy
2	Intense, anxiety-inducing, evoked raw feelings, uncertainty	"I... felt like the piece brought a lot of uncertainty about when it would end, due to how the tension was spread through the different movements. This somehow was also very true of the pandemic."
3	Fright, anxiety, darkness, and loss of hope	(1) Performance dynamics; (2) instrumental sonic diversity; (3) "the use of Jessica's loud breaths during the performance, and I really believe that human voice, even more in the middle of a purely instrumental piece, brings a great emotional charge"
4	Suffering, panic, an emotional journey (rise and fall of isolation and tension)	(1) Final heavy breathing motif; (2) characters created by the instruments
5	Tension and release (metaphor of waves) and the passage of time	(1) Musical build towards climax where the musicians "gasped for breath" and (2) Short, rhythmic pulses
6	Isolation and attempted connection	The performers' connection
12	Disease progression, hope at the end	N/A
18	Uncertainty	"Breathing and percussive techniques bring the themes forward"
19	Stress, uncertainty, unpleasantness	Shrill tones

features that elicited specific emotions (Table 5.4), though some responses were a bit more overarching, such as the participant that stated:

> Things really began to click for me near the very end, when both performers drew strained breaths. At that point, the meaning of the piece began to set in. I think it was especially poetic given that these kinds of experiences only make sense in retrospect. The connection between the performers was also powerful all throughout—it felt like it really tied the narrative together, the idea of these two forces within one person trying to recover, or two people on parallel journeys through illness and trauma.

A selection of audience members also provided specific feedback regarding what they thought would have brought the piece closer to their ISQ responses, including "Maybe it was missing a little bit of hope?", "All of the feelings I described earlier could maybe be even more

accentuated through more use of the voice [to bring more 'emotional charge' to a purely instrumental piece]", and "I would be interested in hearing the isolation of the two sonic worlds [of the two instruments] from each other to remind me of the COVID isolation."

This, in itself, demonstrates the importance of personalization in music-centered affective work. Each audience member listened to the same piece at the same time in the same room performed by the same musicians, and yet, the expectations and emotions they brought to the experience varied so greatly. Though this serves as a single example of this variation, this work serves as an indicator of the variety of perspectives, prior experiences, and expectations that listeners bring to music experiences, highlighting the importance of developing strategies, tools, and interventions that consider and account for these influences.

5.3 Conclusions

Overall, the five projects mentioned here demonstrate different facets of the role of music in expression, whether that is on the part of performers, composers, audience members, or workshop participants. The Music and Well-Being workshop highlighted the value of personalized, music-centered, community-focused outreach to promote a sense of agency over one's own mental health and well-being, especially when it provides opportunities for creativity and self-expression. The series of audience surveys conducted during the performances of *Breathing Together*, the *Wellbeing Concerts at Carnegie Hall*, and *The Distance Between Us* all served as iterative steps towards identifying the ideal method of assessing the impact of live music on well-being in real time. Through this work, we found that, in these small-sample studies, the majority of the general public who were not professional musicians reported that listening to, performing, and interacting with music had a positive impact on their mental health and well-being. This supports our hypothesis that this reaction would occur, especially when such interactions with music were framed as experiences created to have such positive, beneficial impacts. However, due to the small sample size of these studies, as well as the ambiguity found in the pilot ICWAS data, further work is required to fully answer ERQ1 and ERQ2. Professional musician populations were

overall a bit more ambiguous than the general population, though anecdotal feedback from the performance of *The Distance Between Us* highlights the value music can hold for self-expression and emotion processing across the board, calling for further investigation into ERQ3. Overall, further work, with larger and more diverse sample populations, is needed to yield stronger conclusions. This thesis, however, serves as both a base point for further research and a checkpoint for the studies that are still in progress.

Chapter 6

Music as Intervention

In this work, intervention is defined as "the act of interfering with outcome or course, especially of a condition or process (as to prevent harm or improve functioning)" [100]. Though the end goal of improving health and well-being remains constant for both expression and intervention, the strategy employed to achieve this goal differs. Of course, these divisions are not finite. After all, though music listening is traditionally used as an intervention to reduce physiological and psychological symptoms of stress and anxiety in clinical settings [140, 56, 77, 109, 110, 155, 79, 15], it is in itself a form of expression, especially when listeners relate to the music they are listening to. It is, however, important to dig further into the applications of music specifically as a validated clinical intervention. As mentioned previously, there are numerous clinical examples of the health benefits of music, though the underlying mechanisms are often uncertain [66]. A deeper understanding of these processes is key to bringing the benefits of music-based interventions to clinical populations, as seen in the structural, neurobiological [136, 20, 19, 54] investigations into the connections between music and emotion. However, as mentioned previously, the potential person-to-person variety found in classifications of anxiety-reducing music highlights the limitations of the current standards in the field. I believe that personalized music-based interventions, which allow users to have control over the music used to positively impact their own affect, have the potential to greatly improve the mental health and well-being of individuals suffering

from a variety of mental illnesses and disorders, including but not limited to anxiety. Thus, the study discussed in this section serves as a proof-of-concept investigation into the utility and impact of such personalized approaches, and sets the stage for further investigation in this space.

6.1 Music, Stress, and Anxiety

This pilot study, conducted with Media Lab collaborators Samantha Gutierrez-Arango, Dr. Neska ElHaouij, Max Addae, and Dr. Rosalind Picard, was presented at the 2023 ACM CHI Conference on Human Factors in Computing Systems in Hamburg, Germany in the Late Breaking Work category under the title "Investigating the Physiological and Psychological Effect of an Interactive Musical Interface for Stress and Anxiety Reduction." Here, we were interested in the concept of *relaxing* music, defined as music that reduces stress and anxiety. We believe that creating a treatment plan around one-size-fits-all "prescription music" fails to consider the impact that cultural background, age, gender, personality, lifestyle, musical training and ability, and prior exposure have on music preference [102, 36, 64, 132, 131, 22, 50, 133, 138] which, in turn, will reduce the efficacy of music-based approaches. Recent work supports this general direction, including Su *et al.*'s Adaptive Music for Affect Improvement (AMAI) [149], which uses game music techniques and music generation to promote positive affect by adapting music based on facial emotion recognition. Similarly to our context, this proposes an adaptive paradigm for music for affect improvement. However, this study automatically adjusted music based on a limited set of initial stimuli that were controlled automatically, whereas we place control in the hands of users to positively impact their own affect. This work also points to the potential value of using physiological measures in this area, which we do in our work.

Grimaud and Eerola's series of experiments [57], conducted concurrently with our work, assess the impact of expressive cues (called "musical elements" in our study) on perceived emotional expression. The researchers employed a system of real-time musical change while avoiding familiarity bias, and emphasized the importance of giving participants the free-

dom to explore emotive music without constraints. In all, this work supports the idea that musical elements can have a direct impact on listeners' perceptions of emotions and demonstrates the value of using an interactive interface in music-and-emotion-centered contexts. In our work, we target the real-world use case of reducing anxiety and stress, and specifically evaluate the impact of music on human physiology and psychology. Additionally, we focused on elicited emotion (how the music makes the listener feel) rather than perceived emotion (the emotion the composer was trying to express), to further emphasize the goal of anxiety and stress reduction.

As such, we assert the importance of personalized approaches to therapeutic music interventions that give listeners increased agency and flexibility to impact their own health. Our research questions were (IRQ1) "Can we shift users' affective state from anxious and aroused to calm and relaxed by allowing participants to modulate musical parameters of a piece, including tempo, rhythm, and instrumentation?" [169, 66] and (IRQ2) "If so, which specific musical parameters lead to the largest physiological indicators of relaxation?" As a first step towards fully investigating this, we conducted a pilot study (N=8) structured around allowing participants to control and navigate through a custom musical interface. The interface features fourteen novel musical fragments with adjusted tempo, instrumentation, and rhythm – moving from anxiety-inducing to happy to relaxing to sad in accordance with our literature review – in order to assess whether we can effectively reduce physiological and psychological indicators of stress and anxiety. We hypothesized that this intervention would more successfully reduce stress and anxiety than when at rest without musical stimulation. We also expected that the impact of the music would differ depending on the musical and cultural background of the listener, which is a part of ongoing work. At the conclusion of this pilot, we collected feedback from our participants and revised our protocol based on our results and feedback. We present our findings to support future work towards building personalized musical interventions that improve symptoms of chronic stress and anxiety.

6.1.1 Methods

Participants

In our pilot study, we recruited graduate students, undergraduate students, and university staff via email lists and class bulletins. We screened out potential participants who had (1) been diagnosed with ADHD and were not currently taking medication, (2) were currently taking anxiolytics, (3) were suffering from severe depression, (4) had hearing impairments and did not have an assistive device, or (5) did not enjoy listening to music. Participants that did not meet any of the listed exclusion criteria were invited to participate in the protocol. Nine participants who met the criteria, aged 18-75, were randomly assigned to either the control or intervention groups. Due to a technical malfunction, one participant's results were excluded, resulting in N=8 participants (four control and four intervention).

Our protocol (number 2110000493), which was approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES), took 30-45 minutes per session. Four of the eight participants identified as male and four as female. Participant ethnicities included South and East Asian, Eastern European, Hispanic/Latino, Caucasian, and African American. Five of the eight participants had received prior music training, and all used music as a tool to relax. All listed music other than Western classical music as their preferred genre for relaxation, with selections ranging from Metal Core to jazz to "anything except rap or country." Participants were compensated with a $15 cheque for their participation, regardless of whether their data was included in the final analysis.

Study Design

Participants initially reviewed the consent form with experimenters and were then instructed to sit in front of a monitor with their hands flat on a desk while experimenters attached one Empatica E4 [1] sensor to each wrist [81]. Our protocol involved deception: participants

[1]More information about the Empatica E4 wristband, used to measure both HR and EDA, can be found in Empatica's online documentation: https://www.empatica.com/research/e4/

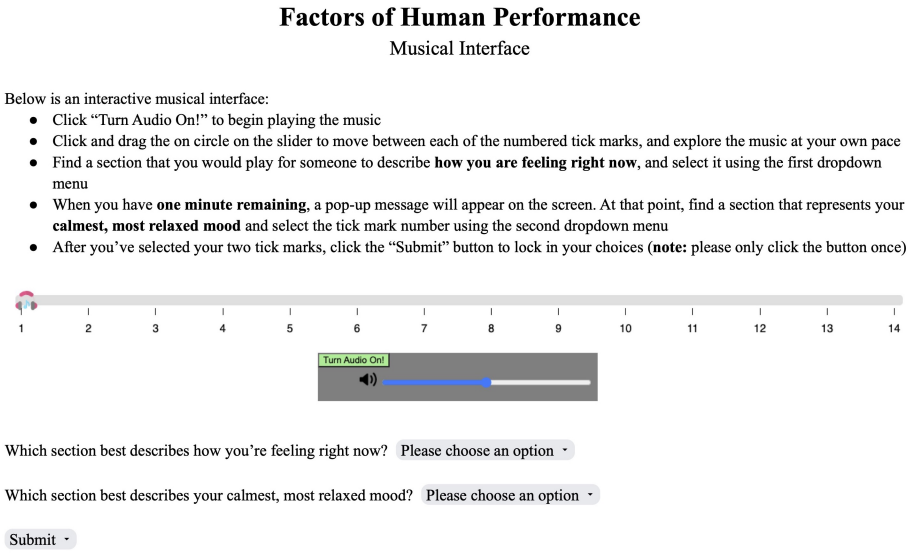


Figure 6-1: In our study, intervention participants used the pictured interface to explore the fourteen segments of music, shown in Table 6.1, and indicate (1) which segment corresponded to their current mood and (2) which segment corresponded to their ideally relaxed mood.

were initially informed that the purpose of the experiment was to investigate the impact of competition on mathematical performance, to ensure the intended effect of the stressor task to promote the validity of our data. Participants were debriefed at the end of the study. Following the stressor task, participants completed a brief pre-study questionnaire, providing basic demographic data as well as information regarding their affective state via (1) a modified GAD-7 [147] survey meant to track recent anxiety (we focused on the prior three days as opposed to two weeks) and (2) two five-point Likert-type items, one each for current stress and anxiety levels, henceforth referred to as the Current Affective State (CAS) survey (Appendix E). Following this, we collected five minutes of physiological data to ensure that we would be able to identify trends that deviated from each participant's baseline [147].

After this, participants underwent a stress-inducing math task (stressor task), where they were given five seconds per question to verbally respond to 60 multiplication problems that appeared on the screen in front of them. Following this, participants completed the CAS survey. Control participants were then instructed to sit in silence and "think relaxing

thoughts" to supposedly collect additional baseline data, while intervention participants were told that one of the experimenters was conducting secondary, unrelated tests of the usability of a new musical interface.

At the conclusion of the study, all participants completed the CAS survey again, were debriefed, and provided feedback. Each participant consented to be video recorded for the duration of the study as well, which allowed us to compare their time-stamped biometric data, the annotated recordings, and our noted observations during data analysis.

Musical Interface

I composed fourteen unique pieces for our interface, to present all participants with novel music, ranging from electronic to pop-rock to ballads, in an effort to avoid bias. We elected to use popular styles to try to replicate some aspects of music present in participants' daily environments while avoiding familiarity bias. We chose to place the musical fragments along a slider bar (Fig. 6-1) to limit the motion of the participants' wrists to a mild left-and-right cadence to mitigate motion artifacts. The graphics of the interface were purposefully made to be stark, in order to avoid any confounding influence from added visuals. This interface was designed to be as user friendly and self-explanatory as possible: since we were collecting EDA and HR data, which we knew would be impacted by the addition of novel stimuli, we wanted to minimize our interactions with the participants as much as possible during the intervention portion of the protocol.

Participants were asked to explore our interface (Fig. 6-1) and identify the tick mark, which represented a set of musical parameters in the composition, that best described their initial affective state (Table 6.1). After identifying this location, they were asked to slowly navigate the interface over the remaining eight to nine minutes, to find the tick mark that best represented what they would listen to in an *ideally calm* state. When one minute was left in the 10-minute duration, a reminder pop-up window appeared at the top of the screen that prompted participants to make their selection of the fragment that described this ideally calm state. Each musical fragment lasted 30-45 seconds on a constant loop

Table 6.1: Description of the musical intervention compositions. Numbers on the left correspond to the tick mark on the interface shown in Figure 6-1. A summary of the musical elements that changed from fragment to fragment is included below, as well as a one word classification of the overarching musical element that was modified – either rhythm, instrumentation, or tempo. We have also provided the style/genre that we believe classifies each piece. We did not provide participants with affect or genre labels to avoid influencing their definitions of "relaxing music."

Tick #	Summary	Element	Style/Genre
1	150 BPM. Staccato synthetic strings and bass. Focus on rhythmic development. Deliberately harsh guitar and trumpet. Synthetic drum pad used to create beats with unfamiliar noise. Music builds to a crescendo for suspense.	N/A	Electronic
2	150 BPM. Staccato strings. Less spatially compressed drum track and bass. Same harsh guitar and trumpet, as well as synthetic drum pad.	Rhythm	Electronic
3	150 BPM. More legato strings, guitar, and bass. Synthetic drum pad is still used. Music is rhythmic, but lacks the urgency found in 1 and 2.	Rhythm	Pop-Rock
4	150 BPM. Exclusion of guitar and synthetic strings. Inclusion of legato flute and LoFi piano. Staccato bass and synthetic drum pad are still in use.	Instrumentation	Pop-Rock
5	150 BPM. Addition of acoustic bass to flute and staccato LoFi piano. Acoustic drum pad used instead of synthetic	Instrumentation	Pop
6	150 BPM. Acoustic strings added to #5	Instrumentation	
7	150 BPM. Twang guitar riff added in place of acoustic strings found in #6.	Instrumentation	Pop
8	150 BPM. Drums and guitar removed. Electric piano riff made up of single, held notes added to #7.	Rhythm	Lo-Fi
9	150 BPM. Extended, soothing synth strings single note added to #8.	Instrumentation	Lo-Fi
10	120 BPM. Tempo of #9 reduced by 30 BPM.	Tempo	Lo-Fi
11	100 BPM. Tempo of #10 reduced by 20 BPM.	Tempo	Ballad
12	100 BPM. Second layer of extended, soothing synth strings added. LoFi piano and flute duet composed of sustained notes replace staccato piano/flute combination.	Instrumentation, Rhythm	Ballad
13	100 BPM. Piano and flute duet shifted into a minor key.	Instrumentation	Dark Ambient
14	80 BPM. Tempo of #13 reduced by 20 BPM. Piano and flute duet replaced by single notes of piano and flute in a minor key.	Tempo, Rhythm	Dark Ambient

for as long as the participant remained on the corresponding tick mark — each time the fragment was played in full is defined here as one *cycle*. We did not provide participants with any of our predetermined affective labels for the musical fragments, in order to control for experimenter bias and to allow participants to come to their own conclusions about what they defined as "relaxing." In addition to this, it has been shown that allowing individuals to have some sort of control over their situation, the previously discussed "locus of control," leads to decreased stress regardless of the scenario [13, 76, 152, 40]. As such, we sought to harness this by allowing participants to control how and when they progressed through the musical composition.

Stressor Task

Our experiment required all participants to feel some level of stress, leading us to develop a broadly applicable stressor task informed by Talevich et al.'s taxonomy of human motivation [109]. We (1) stationed an experimenter next to each participant as they answered the questions, (2) informed them that they were being compared to their peers and coworkers at both their home institution and at a rival school, (3) called the multiplication problems "basic" when introducing them, (4) motivated participants to think more carefully about their answers by requiring them to say "the answer is..." before responding, and (5) promised and provided an additional $30 reward to the participant with the highest score.

In the pre-study questionnaire, six of the eight participants reported enjoying mathematics, with an even split of preference for written or mental calculations. All participants had studied mathematics at or above Calculus-level difficulty. Since all of our participants had high-level mathematical experience and many of them had either completed or were in the process of completing engineering degrees, it was vitally important to target as many facets of motivation as possible. This, we believe, helped to ensure the success of our stressor task, by avoiding the assumption that all of our participants would find the same aspects of the task to be equally impactful.

6.1.2 Results

Questionnaire Data

GAD-7 Scores Though participants were randomly assigned to control and intervention groups, all control participants had significantly higher GAD-7 scores (6.8 ± 2.8) than our intervention group (2.5 ± 1), scoring mild-to-moderate and minimal self-reported anxiety respectively (two-tailed t-test, $t(14)$=-2.90, p=0.02). Since this provides a baseline of longer term anxiety, we report this result to provide more context on our participant pool.

Self-Reported Stress and Anxiety Despite the presence of significantly higher pre-study stress in the control group compared to the intervention group (Wilcoxon-Mann-Whitney, U=0, p=0.02), there was no significant difference in reported stress between both groups after the stressor task (Wilcoxon-Mann-Whitney, U=5, p=0.38). Ultimately, at the end of the experiment, participants in the intervention group reported significantly less stress than participants in the control group (Wilcoxon-Mann-Whitney, U=1, p=0.04). However, though we identified these self-reported differences in *stress*, there was no significant difference between the two groups' self-reported *anxiety* pre-study (Wilcoxon-Mann-Whitney, U=3, p=0.15), post-stressor (Wilcoxon-Mann-Whitney, U=4.5, p=0.31), or post-study (Wilcoxon-Mann-Whitney, U=4, p=0.24), as seen in Fig. 6-2, despite the groups' significant differences in long-term anxiety identified in the GAD-7 results.

Physiological Data

The physiological data (shown in Fig. 6-3 for two representative participants) can be grouped into seven main periods, described from first to last as (1) the sensor application and pre-study questionnaire, (2) the five-minute-long **baseline**, (3) the stressor task instructions, (4) the **stressor** task, (5) the completion of the first CAS survey followed by control/intervention instructions, (6) the control/intervention task (**condition**), and (7) the final CAS survey and participant debrief. For the control participant, the largest spike in

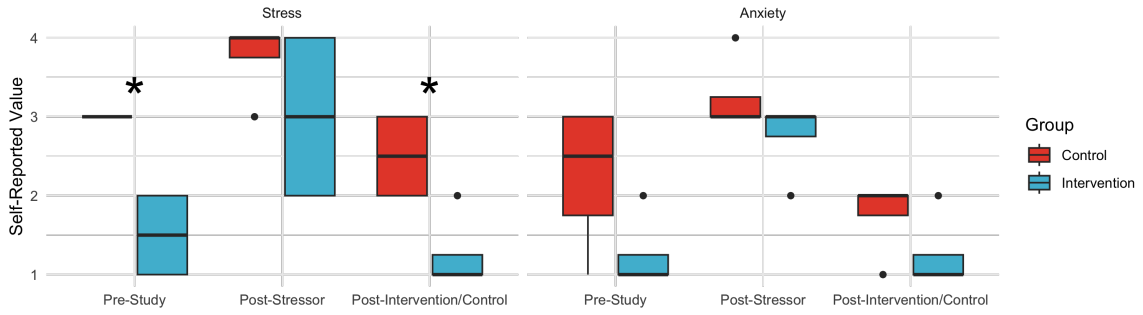


Figure 6-2: Participants' self-reported stress and anxiety pre-study, after the stressor task, and after the study. These results used between-group comparison. **(Left)** Self-reported stress – Control participants initially had significantly higher self-reported stress than the intervention group participants (Wilcoxon-Mann-Whitney, U=0, p=0.02). After the stressor task, there was no significant difference between the two groups' self-reported stress (Wilcoxon-Mann-Whitney, U=5, p=0.38). However, after the intervention/control period, the intervention group reported significantly less stress than the control group (Wilcoxon-Mann-Whitney, U=1, p=0.04). **(Right)** Self-reported anxiety – there was no significant difference between control and intervention group anxiety pre-study (Wilcoxon-Mann-Whitney, U=3, p=0.15), post-stressor (Wilcoxon-Mann-Whitney, U=4.5, p=0.31), or post-study (Wilcoxon-Mann-Whitney, U=4, p=0.24) despite the groups' significant differences in long-term anxiety identified in the GAD-7 results.

both EDA and HR occurred either just after or during the math task respectively, highlighted by Circles 2 and 4. Circle 5 highlights a major spike in EDA in the intervention participant at a moment when they forgot to state, "The answer is..." before providing the answer to the arithmetic question. When the experimenter corrected them, the participant responded with verbal, facial, and body posture indicators of surprise. We show these as examples of the overall physiological data we analyzed for differences.

By accounting for events such as those we annotated and comparing the biometric arcs of control and intervention participants, we observed that the intervention may result in higher arousal levels than the control condition. This was a surprising finding that we discuss in more detail in future sections. We hypothesize that this may reflect difficulties in disentangling stress and anxiety from other high arousal affective states, such as excitement and interest.

Interface Data Collection

We used participants' interaction data to compute the average frequency of visits and duration of time spent on each tick mark, shown in Figure 6-4. Tick marks 11 and 12 show

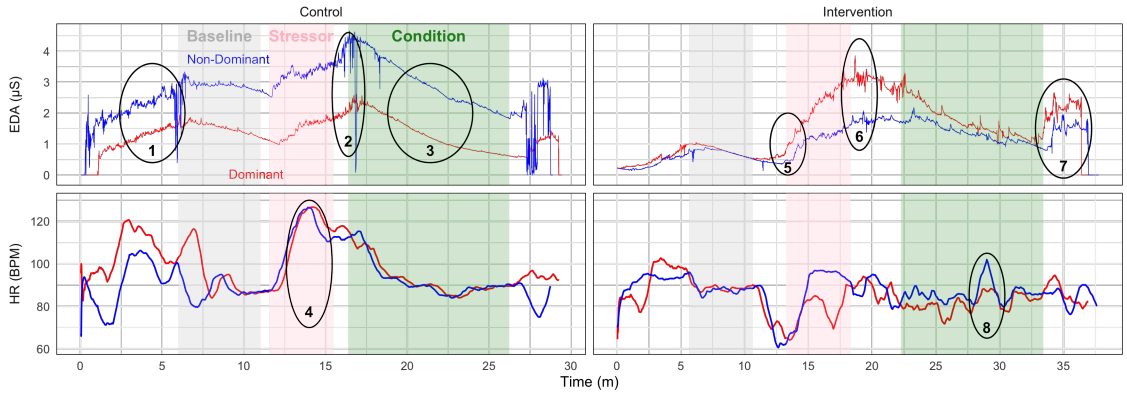


Figure 6-3: Comparison of electrodermal activity (EDA) in microsiemens and heart rate (HR) in beats per minute from representative intervention and control participants. Red lines indicate readings from the dominant hand, while blue lines indicate readings from the non-dominant hand. Black circles indicate significant events observed by the experimenters, which were confirmed via video data. Circles 1-4 annotate control data. 1 indicates a spike in EDA during the pre-study questionnaire. 2 indicates the largest spike in EDA during the protocol. 3 indicates a decrease in EDA consistent with relaxation that occurred when the participant was reportedly "listening to music in [their] head." 4 indicates the highest spike in HR during the protocol. Circles 5-8 annotate intervention data. 5 indicates an initial spike in EDA that occurred when the participant was corrected during the math task. 6 indicates the largest spike in EDA during the protocol. 7 indicates the moment where the participant was debriefed on the true purpose of the experiment. 8 indicates the moment where the participant believed that the interface had broken due to forgetting usage instructions. We provide these annotations to show how we identified events and patterns in the physiological data.

particularly high levels of engagement, averaging around 1.5 minutes each of total play time during the intervention. We also recorded the tick mark number corresponding with the submitted initial and ideal calm state fragments. *Current* states diverged from one another (P1: 4, P2: 9, P3: 3, and P4: 6), whereas *ideal calm* states were more similar, despite still exhibiting some variation (P1: 12, P2: 12, P3: 9, and P4: 11).

6.1.3 Discussion

Musical Elements

Participants' self-reported data supports our overall approach, since the intervention group reported significantly more stress-reduction than the control group and EDA generally decreased during the musical intervention. However, it was difficult to determine the impact of specific musical elements in our pilot study, which suggests a needed refinement to the interface to more readily identify such factors. The control group's EDA was overall lower

than the intervention group, as compared to their individual baselines, suggesting lower arousal. Note that this does not necessarily indicate less stress; it is possible that the use of this musical interface results in high arousal, high valence affect, such as excitement and pleasure. The self-report data indicates higher valence, supporting this interpretation.

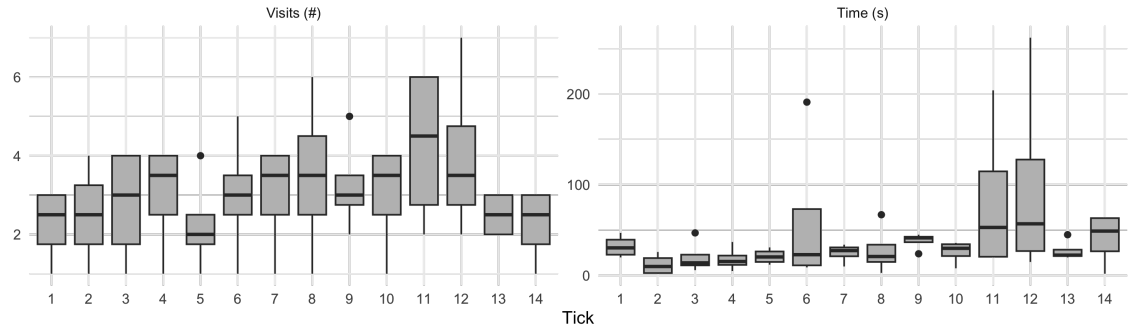


Figure 6-4: Participant-interface interactions. **(Left)** Number of times intervention group participants visited or re-visited each of the musical fragments during the ten-minute-long intervention. **(Right)** Time participants spent on each musical fragment. On average, participants spent the majority of time on tick marks 11 and 12, which were characterized by slightly slower tempos, more soothing instrumentation, and slower rhythms (Table 6.1).

Study Sample and Data Analysis

Since our work presents a small-sample pilot study to address this challenging problem, we were unable to obtain significant conclusions in some aspects of our evaluation. Given both this limited sample size and the scope of this pilot study, we elected to conduct a between-group comparison with plans to conduct both between- and within-group analyses during our full experiment. We emphasize that this work serves as an initial, exploratory analysis to provide preliminary insight into the impact and effects of our proposed intervention, which will guide our future work. In other words, this pilot serves as a first step, supported by self-report data, physiological data, and our observations, that validates the goal of this work: to design user-controlled music interfaces as a viable, personalized anxiolytic intervention. In future studies, it is essential to recruit a larger, more diverse sample, composed of a variety of social, cultural, and ethnic backgrounds, to reach grounded and representative conclusions about the impact of personalized, user-controlled musical interfaces on anxiety reduction.

Data Collection

By extracting a greater range of possible anxiety markers from measures such as EEG, fMRI, and video analytics (e.g. posture detection, fidgeting, etc.), this work could more robustly assess the impact of our approach on participants who exhibit diverse symptoms. We also note the importance of capturing more detailed demographic data, with respect to native languages, cultural backgrounds, and musical exposures. For instance, our pilot emphasized English-speaking participants in a way we did not anticipate. All participants who were not native English speakers mentioned that the stressor task was especially difficult since they learned arithmetic and, thus, performed mental calculations in their native languages. The added effort of conducting translations may have led to unaccounted-for differences in induced stress. Finally, we observed that some participants exhibited higher arousal during the pre-study questionnaire than during the stressor task. As such, we must collect baseline data before conducting the pre-study questionnaires, to keep the impact of introducing novel stimuli on physiology from influencing this measure.

Cognitive Load

Control participants sat in silence for the same time that intervention participants interacted with the interface. The collected EDA shows that intervention participants had higher arousal than control participants. However, the self-reported survey data shows that, after the study, intervention participants were actually *less* stressed than control participants. HR data supports this – the HR of intervention participants either remained the same or decreased during the intervention, despite the spike in EDA. This suggests that participants were *stimulated by* or *interested in* the interface, but not necessarily stressed. As such, creating a control condition that matches the cognitive load of the intervention condition is important when controlling for the arousal spikes derived from interacting with novel stimuli, to be able to make clearer conclusions about the impact of the musical interface.

Exploration Time

Relatedly, it would be useful to allow participants to explore the interface for one to three minutes prior to beginning the official control or intervention data collection. As mentioned before, we noticed several spikes in EDA in our participants that did not correspond to elevated heart rate, which suggests arousal caused by exposure to novel stimuli rather than stress. We expect that giving participants time to explore the interface beforehand would control for these anomalies, to ultimately allow us to more clearly observe the impact of the personalized application of music on the participants' biometric data.

Music Length and Composition

Currently, each musical fragment is approximately 30-45 seconds long and plays in a loop until the participant switches to another tick mark. Though some participants elected to linger on fragments for upwards of five cycles of the piece, others would remain for one to two cycles and move on to a different tick mark. In the future, it is important to compose longer pieces of music to allow participants to spend more time with the piece while controlling for repetition fatigue. We also believe that it is important to dig deeper into investigations of the impact of musical elements by, for example, using more varied tempi and rhythms. Relatedly, in this study, we elected to compose using features from popular music in order to try and replicate some aspects of music present in participants' daily environments while avoiding familiarity bias. In future studies, we would like to explore additional genres, to gain a better understanding of the impact of musical preference, as well as styles outside of the Western musical space, on user interactions with this interface. There is also notable potential for the use of generative approaches to personalized music for affect change, which could be further supported by considerations and analyses of physiological data such as what we have discussed here [149].

6.1.4 Conclusion

We reported on a study centered around a personalized musical intervention for anxiety and stress reduction. The intervention was deployed through an interface containing fourteen novel musical excerpts which we composed to vary along musical dimensions of rhythm, instrumentation, and tempo to positively impact affect. We used a combination of self-report and physiological data to assess the effect of this interface, with initial results that suggest potential benefits of our approach for reducing anxiety and stress, though more work is needed for full evaluation. This serves as a small-scale proof of concept study demonstrating that musical interventions can reduce stress effectively when delivered through an interface that allows participants to personalize their musical stimuli. Our results suggest that there is value in conducting larger-scale studies, to draw firmer conclusions from protocols such as this. Such work must assess the impact of changing key musical elements, to ultimately evaluate the utility of making personalized music-therapeutic interventions available to a broad population of users in ways that are equitable and accessible.

Chapter 7

Limitations

It must be noted that each of these studies serves as a pilot for further work which, thus, calls for larger-scale experiments with more diverse populations, especially culturally, racially, linguistically, and ethnically. As mentioned previously, this is a vitally important facet of any future work, due to the diverse backgrounds, ideas, and prior exposures that listeners bring to musical experiences, as exemplified by the results of the *The Distance Between Us* pre-concert ISQ (Fig. 5-8). Limitations in this work generally relate to study samples. While we were able to recruit relatively diverse populations for each project, the sample size for each was limited and drawn from preselected communities, whether that was from MIT or the populations served by our partner institutions and organizations, which in itself leads to some uniformity.

Time- and environment-based limitations also impacted this work – testing of the anxiety-reducing interface was restricted to an hour in an isolated lab space. While this strategy was necessary to control for confounding variables, it is not reflective of the ways that people listen to and interact with music in their daily lives. Further work that draws influence from neuroethological principles is necessary, to gain a better understanding of the ways that music impacts mental health, whether that is neurally, psychologically, or behaviorally. In other words, in the future, it will be important to blur the lines between "expression" and "intervention" more, to gain a more in-depth perspective on the applications and efficacy

of this work in real-world contexts. Along this line of thought, it is also important to study the long-term impact of music, beyond what is possible during a single, finite experimental session, to gain a full understanding of the potential of music as a mental health intervention.

Chapter 8

Future Work

8.1 Music and PTSD

In the future, I hope to use my anxiety- and mental-health-centered work to build towards developing novel interventions and symptom control strategies for Post Traumatic Stress Disorder (PTSD). Approximately 6% of the US population will experience PTSD in their lifetimes, defined as "an emotional response to a terrible event like an accident, crime, or natural disaster," generally consisting of persisting feelings of stress and fear following a prior traumatic event, during scenarios that would not normally induce such feelings [8, 119, 117]. Symptoms include but are not limited to flashbacks, nightmares, avoidance behaviors or thoughts, feeling "on edge", difficulty sleeping, negative thoughts about oneself and the world, fatigue, nausea, headaches, and loss of interest in enjoyable activities [117, 41, 29]. Such symptoms must "last more than a month and be severe enough to interfere with relationships or work" for a patient to receive a diagnosis [117]. PTSD and anxiety share both psychological and physiological symptoms and patterns of activation, the latter of which include notable change in ANS functions [143, 154, 145]. More specifically, sustained hyperactivation of the sympathetic nervous system (SNS), which is a division of the ANS, is a hallmark of PTSD – symptoms include elevated HR, blood pressure, and EDA [145].

Anxiety and PTSD both present clear, at times similar, patterns of structural activation.

The amygdala, which serves as the brain's focus for processing fear-based emotions and memories, is hyperresponsive in patients suffering from both PTSD and anxiety [122, 33, 95]. Both conditions are also tied to activation of the limbic system which, as mentioned previously, "integrates the sensory, affective, and cognitive components of pain and processes information regarding internal bodily state" [95, 63, 43]. The HPA axis, which serves as the primary endocrine mediator of stress responses, is directly associated with the presentation of both PTSD and anxiety disorders [122, 95]. According to prior work, the ventral frontolimbic brain regions of individuals suffering from PTSD, which include the ventromedial prefrontal cortex, the inferior frontal gyrus, and the ventral anterior cingulate gyrus, are noticeably more activated than those of individuals without PTSD [122, 95, 107]. Furthermore, PTSD-induced sensory gating deficits have been associated with hypervigilance and hyperarousal, with studies highlighting abnormal patterns of activation in the left ventrolateral prefrontal cortex and the frontotemporoparietal cortical network that noticeably differ from normal activation during inhibitory processing [122, 95, 42].

Current treatment plans for PTSD involve some combination of medication management and psychotherapy, which may include exposure-based cognitive behavioral therapy (CBT) and eye movement desensitization and reprocessing (EMDR) according to the American Psychology Association (APA)'s treatment handbook [93, 125, 139, 156, 122]. Other treatments, such as stress inoculation training, cognitive processing therapy, coping skills therapy, eclectic psychotherapy, psychodynamic psychotherapy, cognitive restructuring, and brainwave neurofeedback, are limited in their generalizability but still offer promising results [83, 93, 125, 156, 122, 16]. As such, it is evident that there is huge potential for novel treatments or complementary therapeutics that are soundly proven to help those suffering from PTSD.

Music therapy provides one such alternate strategy, especially since music reduces cortisol levels and subjective reports of stress, increases dopamine release, and promotes feelings of community connectedness – all of which can help mitigate PTSD symptoms [27, 166, 53, 59]. The use of active music instruction as a complementary therapy to traditional treatments has shown huge potential for reducing average PTSD severity and depressive symptom

scores [125]. Playing and listening to music demonstrated potential to "stimulate neuroplasticity and neurogenesis, enhance brain recovery, normalize stress response... improve coping and emotional regulation, decrease dissociation symptoms, reduce depression and anxiety levels, and overall reduce severity of PTSD symptoms" [122]. However, despite this noted promise, there is need for more work that identifies the specific elements of music therapy that are the most important for effective treatment, whether that is, for example, venue, symptom presentation, or activity, across clinical subpopulations and "age, gender, index trauma (e.g. sexual, combat, terrorism, natural disaster), complex or isolated trauma, socioeconomic background, and existing musical ability or training" [83, 122]. Though the work in this thesis does not specifically focus on PTSD, it serves as an important first step towards creating sorely needed music-based interventions for PTSD, especially given the aforementioned physiological and psychological overlap with symptoms of anxiety.

8.2 Music and Anxiety: A Case for Personalization

In order to develop actionable tools for anxiety and, eventually, PTSD mitigation, it is important to understand the impact of personalization as compared to traditional applications of music-centered intervention, such as passive listening. Though the pilot study highlighted an interesting relationship between music, physiology, and behavioral data, it was difficult to parse whether the positive effects were due to the presence of music in general or the personalization itself. As such, it is important to separate these factors, to gain an understanding of whether personalization offers a comparative advantage. Utility and usability are two key considerations when developing novel mental health interventions – after all, the attrition rate of digital mental health tools is staggering. For example, in a study of 93 non-FDA approved well-being-focused Android apps, the median 15- and 30-day retention rates were merely 3.9% and 3.3% respectively, with a daily active user rate of about 4% [4, 115]. As such, there is massive need in the digital mental health space to create technology-based mental health interventions and tools that promote user engagement and hold users' attention. Music serves as a promising medium to achieve this goal due to the prevalence of music listening, both in live settings and via the music streaming industry, which is thought

to have more than 616 million users and counting globally across platforms [151]. However, the majority of physiology-centered prior work relies on experimenter-selected examples of relaxing or "positive" music [140, 56, 77, 109, 110, 155, 79, 15] that do not consider the backgrounds, cultures, traumas, and prior exposures of the participants. As such, the research question (IRQ3) of this follow-up study that will be completed during the summer of 2023 is as follows: "Are personalized approaches to music-based anxiety interventions significantly more useful as mental health interventions than traditional applications of music in therapeutic settings?" We hypothesize that participants will find the personalized approach to be significantly more anxiety-reducing than the traditional methods of predetermined music, largely due to the control and agency afforded by the more individualistic approach. This protocol (number 2302000912), which was approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES), will run during the summer of 2023.

8.3 Clinical and Neurophysiological Research

Though we are able to gain a plethora of valuable insight from biometric data, it is important to also gain an understanding of neural activity, in order to fully support any conclusions about the impact of proposed interventions. Functional magnetic resonance imaging (fMRI) serves as one example of many such methods of measurement, and allows us to assess the functional connectivity and activity of specific brain regions [122]. Since anxiety, as well as PTSD, present clear patterns of structural activation, fMRI is a useful, direct way to assess patterns of neural activity pre-, during-, and post-intervention, to allow for deeper understanding of the efficacy of proposed solutions. Electroencephalogrphy (EEG), which measures the electrical activity of the brain, presents another common, non-invasive measure of neural activation that has proven use in both music and mental health studies [31]. Hormone testing, such as cortisol measurement, also provides an additional interesting avenue of study in this musical context.

Relatedly, once these music-based interventions are adequately tested, it is vitally important to navigate through the steps necessary to deploy these tools in clinical practice. A longer

term goal for this research is to partner with clinicians to work with clinical populations, with potential to upgrade to a clinical trial. As we have seen through prior work and the work conducted for this thesis, music holds enormous potential to improve the lives of those suffering from a variety of illnesses and disorders. By validating these interventions and operating through these official, strenuous channels, we have the opportunity to profoundly shape the mental health and well-being sphere by deploying scalable, accessible, affordable interventions.

8.4 Generative Music

Generative music has become a hot button issue over the past few months, particularly in the wake of MusicLM [2] and the viral "Heart on My Sleeve" track released on streaming services that used AI-generated versions of Drake and the Weeknd's voices with notable success [34]. Conversations surrounding the relationship between art and generative AI have hit a boiling point, with, for example, artists filing class-action lawsuits against Stability AI, the creators of Stable Diffusion, for alleged breaches of copyright and illegal image scraping [69]. OpenAI's ChatGPT has also been the center of recent news cycles, with press covering a massive spectrum of ChatGPT's current and future abilities, from predicting stock moves [84] to screening for breast cancer [61] to "scare[ing a user's] landlord out of an unfair rent hike" [65] to transforming the workforce [90]. Given the prevalence of AI in the global psyche, it would be remiss not to mention the potential applications of generative music for mental health and well-being. AI-based affective music generation (AI-AMG) systems are on the rise and are thought to:

> ...Have certain benefits compared to human-created music, such as the ability to skirt copyright issues, the computational means of blending genres/musical elements in novel ways, and in the case of real-time music generation systems, the ability to flexibly tailor the generated music to aspects of the environment or changes in the listeners' physical or emotional state... [and] are potentially

> capable of creating an infinite number of unique affective music compositions, and composing music without any associated time constraint [165, 35].

However, despite advancements made in this space, there is still much to be explored. Importantly and relevantly, many AI-AMG systems are unable to perfectly replicate users' desired emotions in a generated piece, which is in part due to a dearth of adequately labelled music-affect datasets [26, 35, 28]. As suggested by Jean-Pierre Briot and François Pachet, as well as Adyasha Dash and Kat Agres, this music-affect intersection is a reinforcement learning problem [23, 35]. Here, one of the biggest considerations is how to identify an appropriate reward signal. One such suggestion for this is through biometric measurement, though the optimal metric to do so is yet to be established and provides a promising and interesting line of future work.

Chapter 9

Conclusion

There is massive need for scalable, equitable, accessible solutions to help combat the current global mental health crisis. Several intervention methods of anxiety management have been explored, including pharmacological treatments, meditation, and biofeedback [55, 168], and, through this, music has emerged as a powerful tool for controlling negative affective state. We conducted a series of experiments and tests centered around the idea that future music therapy-focused technologies and methods of data collection must be grounded in personalization, to give listeners the agency and flexibility to control what is defined as relaxing, anxiety-reducing, or simply helpful for them, in order to improve their own mental and physical health.

Ultimately, each of the projects discussed here inform the others: the lessons learned from the *Breathing Together* survey informed the structures of the surveys for the *Wellbeing Concerts at Carnegie Hall* and *The Distance Between Us*. Relatedly, the personalization strategies underlying the ICWAS survey were built into the open response questions for *The Distance Between Us*. The guiding principles of personalization, agency, creativity, and user-control that inspired the music and anxiety interface intervention led to the creation of activities for the Friends of the Children workshop. Both of these projects in turn served as evidence for the relationship between music and emotion processing, which was central to the *The Distance Between Us* composition process.

As such, the connections among these projects collectively yield the novel contributions of this work:

1. A method of audience self-report data collection during concerts and performances that is grounded in the principles of both individualization and flexibility. The discussed strategy provides a method of naturalistic, in-the-moment data collection, as opposed to the traditional retrospective approach, which allows researchers to begin to understand the real-time impact of live experiences on their experimental populations while controlling for hindsight bias.

2. A graphic-based method of musical notation that is grounded in health-related imagery, as well as a strategy for composing with this method.

3. A composition using the technique and notation style discussed in (2), with provided descriptions of the process, an archival recording of the live performance by musicians Jessica Shand and Charlie Lovell-Jones, and an analysis of feedback from the audience and performers.

4. An interface for and implementation of personalized applications of music to modulate physiological and psychological symptoms of anxiety. The work discussed here serves as a proof of concept experiment with extensive data collection showing initial results, as well as reflections on the lessons, next steps, and applications of this work.

5. Five unique projects in the music for mental health space that collectively provide insight into and work towards demonstrating the importance of creating personalized strategies that work at the intersection of music for intervention and expression.

The thread that connects all of this, however, is that of personalization. The importance of considering the individuality and varied experiences of users, patients, performers, and audience members while providing them with a locus of control, to promote their agency and allow them to impact their own affect, cannot go understated. This, I believe, is where the future of music for mental health lies.

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Appendix A

Breathing Together Audience Responses

Please note: the responses provided by the musician that performed in *Brain, Body + Breath* are italicized.

A.1 Question 1: How does music impact your emotion? (i.e. helps with emotion processing, helps you express yourself, etc.)

Table A.1: Participant responses to Question 1 of the *Breathing Together* survey.

Participant	Response
1	*I like listening to drones/frequency music for stability and peace. Otherwise, I will get too deep into this answer for all the other things I listen to for a specific purpose.*
2	Deeply - I use music to help me transition between moods
3	As a musician, music enables me to describe and express emotions that I can otherwise only vaguely describe via spoken or written language. As a music listener, music helps me realize, re-experience, or experience anew, emotions that I perceive in (or project onto) the music.
4	Extremely deeply. I actively use music to modulate my emotion–as you said in the question, to help with emotion processing, but also to relive and process memories, to motivate myself, to create an environment that feels more resonant to my current affective state, as a way to explore myself (what new music is resonant to me, for example), as a way to deepen the cinematic meaning of physical spaces, etc. As someone who produces music, I also use music as a textural, semi-architectural playground for wandering around my innermost experiences: timbres and automations become these intense motors for pulling at my heartstrings, and instruments and vocals become a meeting place between raw authenticity and tactile input. Sometimes, something–more often something I hear than something I'm creating–is so emotionally resonant (very literally ring true) that I'll briefly be moved to tears, or get chills across my entire body (the latter occurs more often when creating, and I figure it likely also has something to do with how my voice moves through my body, and the former occurs more often when listening). Music also seems to have a strong bearing in social settings, but I find myself less personally connected to that–I hesitate to share my music tastes because they don't tend to be very good at creating a positive atmosphere interpersonally (they're either mildly eccentric or too sad or aggressive), and because of how they might be perceived, but when I share music I create, the emotional alignment between myself and others is sometimes powerful.
5	Express myself
6	Relaxes me
7	depending on the type of music i'm listening to, i find myself emulating the emotions of the song - if i'm feeling sad but turn on happy music, after a bit, i feel more energized. I'm not a musician, so music doesn't necessarily feel like a tool for self expression.
8	It has the ability to help me access and process emotions. It can completely change my mood. It can help me relax. It can make me want to dance.

A.2 Question 2: Does attending a live performance increase or decrease your emotional connection to music? If you are a performer, does playing live impact your emotional connection to music?

Table A.2: Participant responses to Question 2 of the *Breathing Together* survey.

Participant	Response
1	*That's so hard to say. I think at this point, what I play has more of an impact on others than on me. Passive listening is often easier for me to engage emotionally with music. If I'm playing, I usually feel I'm in my left brain at least some of the time, and often, all of the time.*
2	Increases - the acoustic is important and surrounds me. The sounds of the musicians playing also decreases my loneliness.
3	My emotional connection to music can vary depending on the quality of the performances I play or listen to. An inspiring performance can increase my emotional connection to music and my desire to play it myself. An uninspiring performance can temporarily decrease the emotional significance I place in music.
4	To some extent. I do feel a deeper sense of connection to the community with whom I'm listening (at least, somewhat–but especially if it's an artist whose to whose music I have a deep emotional connection), and a substantially clearer sense of how the performer embeds their vision, if not also their emotion, into their music. There's something to be said about liveness, too–about singing along, about being there, about the music moving through you physically. But I find listening alone in private places with great headphones to be similarly moving. Visuals I think help in some cases, depending on their aesthetics, which is part of why I find DROELOE's work to be so compelling: they tell a story that I can't help but feel has grown to be woven into me and my own experiences.
5	Increase both as attendant and performer
6	Increases
7	I don't know - I like going to live performances and i think i'm probably more engaged bc i'm not doing anything else in that moment, while usually when i listen to music, it's while doing other things.
8	Increase, as an audience member and whenever I perform (rarely).

A.3 Question 3: Name an artist whose music you connect to emotionally. Why do you connect with this music? Is there a specific time where the music connects more? Is there a specific song?

Table A.3: Participant responses to Question 3 of the *Breathing Together* survey.

Participant	Response
1	*Freddy [sic] Mercury is one of many I could point to as being emotionally engaging. I need to be in a relaxed space to listen and be receptive to emotional qualities generally. His passionate singing and ability to make a musical phrase are the main reasons I like to listen to him.*
2	Joni Mitchell - Jaco's bass playing especially at the end is quite grounding but also freeing. This particular song reminds me that lif [sic]
3	Ambrose Akinmusire. His early recorded albums were the albums that I listened to most deeply while I was learning my instrument and during my adolescence. I also think that his music is intentionally maximally emotive. For that reason I connect with his music in my most contemplative moods, and usually do not otherwise listen. "Ruby" is a nice, emotive composition.
4	I'll never forget the emotional experience of stumbling upon and hearing OKADA's "The Right to Destroy Myself" for the first time. I think it popped into my Spotify queue while I was working at home, but the way it reached me felt much more important than the setting itself. Much of it starts out unassuming–although there are these haunting, slightly bass-y voices that I think are what it might sound like if a choir of ghosts had come to slowly siphon the life from you and watch you grow pale–but eventually, a haunting piano motif returns and a woman's whispered voice enters the soundstage as intimately as possible. It hit me like a bag of bricks. The words were resonant in a way I wasn't expecting while going through a difficult time but trying to get work done. I now revisit that song when I'm looking to process the weight of a difficult emotional experience, or when I need emotional space to just exist with myself. There are others, of course–some artists I grew up with and remind me of how my thinking and identity have evolved over the years, some artists' work I've found to be deeply motivating, and some artists' works have appeared to me (yet again by the mighty and fickle hand of the Echo Nest) while I'm in transitory spaces–whether literally and physically or emotionally–that now make them forever associated with those moments and all their tossing and turning and twisting.
5	Aretha Franklin killing me softly [sic]
6	Freddy [sic] mercury [sic]. Liberating
7	I love the artist Aly Halpert right now. her album Loosen has been really soothing and supportive during a challenging time, and i [sic] feel a connection to the artist because we share certain identities that are important to me.
8	Brahms. I just love the colors and the way he emotes. I feel like he helps me access a place deep inside me.

A.4 Question 4: Please describe your emotional reaction to *Breathing Together*. Were there specific moments you connected to? Found too jarring? Did/would knowing the emotions behind the piece help you connect more?

Table A.4: Participant responses to Question 4 of the *Breathing Together* survey.

Participant	Response
1	*I think understanding the story emotionally could help, not always, but possibly. My emotional reactions were enjoyment and pleasure at playing acoustically among ensemble members, where we needed to depend on one another to communicate in order to produce the whole.*
2	I connected with the flute playing and the gestures of in and out (up and down) bowing. There were portions when everyone was playing and I lost track of the breathing mechanism.
3	Understanding the concept behind the piece enabled me to be aware of my breathing during the piece. I did not find the piece too jarring. I found myself holding my breath during moments of excessive or quick breathing, and breathing more slowly during longer, sustained or legato sections.
4	I regret that I'm filling this out a few days after listening to Breathing Together; my response might be skewed. Perhaps because I heard it many times during rehearsals, or perhaps because I was primed by VocaGammified and more cerebral discussion of what the pieces meant, or even because of the piece's many technical flairs, I felt less emotionally moved by the piece. I do remember some quieter moments–I *love* the very gentle and almost dissonant but still homebound progression on strings in the outro just before Jess and Yuma come in with the final held note–and some others that I think are in the first minute or so of the piece (not quite the very beginning, but a bit after just as the strings are coming in). Other moments were more jarring indeed–especially those in which the melodies were more discordant, the quartet snapped their strings (there's probably a proper term for this but I don't know it), etc. Nonetheless, I did eventually find that I felt as though I was breathing with the ensemble. Perhaps it was closer to that improvisational section where that was intended, but at least about 3/4 of the way through the piece, I felt somewhat in sync with it. I also at least intellectually felt some resonance between the piece and the arc of your piece, Kimy, for the "new understanding of music" assignment in MAS.825J: there was the normalcy and vibrance of life, the jarring silence of breathing becoming dangerous, the slow and dark recovery of a world that will never quite be the same. I think I did physically and emotionally feel the relief when the music settled back into more harmonious stretches in the third of those passages, but apart from that, it was again a more intellectual appreciation and understanding of the message (perhaps not knowing the emotions behind the piece would have helped, or knowing the emotions rather than the ideas behind the piece would have been better–although, that in itself raises questions of whether the ideas and emotions are fundamentally related or not, and which better expresses the other).
5	Too hard to find words
6	Did help me connect me. Founds parts where breathing is as strained jarring. Interspersed normal breathing was a welcome break
7	filling this out the morning after, so it's hard to remember all of the specifics. i was really struck by the moment when it all got quiet and the flutist started to breath on her own again.
8	The flute soloist was a star. I loved her playing and her ability to connect with the audience using her gaze. She was extremely powerful. There was one particularly long note in the clarinet part with a crescendo that made me want to inhale deeply.

A.5 Question 5: Is there music you've heard that you believe best helps you describe or process the emotions that the COVID-19 pandemic has elicited? How/why has that music connected with you the way it has?

Table A.5: Participant responses to Question 5 of the *Breathing Together* survey.

Participant	Response
1	*No.*
2	I listen to a lot of meditation tracks and feel the most calm when listening to nature sounds. I think because it is connected to the earth and not man made acoustic experiences.
3	Orange - nthng. The process of being put under lockdown and indefinitely remotely working was numbing, an emotion (or non-emotion) that I think this track evokes.
4	Absolutely, but it feels more aligned with the general process of coming to terms with myself and building new neural connections in a changed world rather than with the arc of the pandemic proper (perhaps because those things were happening simultaneously for me as a young adult during quarantine). During my lowest lows, music pulled me lower–or perhaps into a safe-feeling awareness of the lowness, the isolation, the distance. Lyrics helped more than they ought to have. Certain minor melodies became home. Progressive house lost its energy and became the repetition I needed to focus in louder moments. I eventually discovered metal, which helped me get through the frustration and aimlessness of the time. Jazz and instrumental math rock have brought me back out into the world: new patterns, new rhythms, new movements.
5	No I'm looking for such music
6	Covid was quite stressful. Music is a welcome release and connects to a time when covid was not present [sic]
7	hmm I'm not sure. I listened to a lot of meditation music from the Plum Village during the pandemic to try and calm myself.
8	Not really.

A.6 Question 6: Is there any additional personal information you'd like to provide about your relationship between music and emotion?

Table A.6: Participant responses to Question 6 of the *Breathing Together* survey.

Participant	Response
1	N/A
2	Music has been a part of my identity from the earliest age, and there is a lot about how and why I communicate in the musical world better than with words or actions that I don't understand. But it is something I need and it is a foundation of how I learn about the world.
3	N/A
4	N/A
5	N/A
6	N/A
7	Thanks for an awesome performance!
8	N/A

Appendix B

In-Concert Well-Being and Affect Survey (ICWAS)

B.1 Questions from the digital pilot of the ICWAS survey from the April 16, 2023 concert. Boxes indicate buttons on the user interface.

B.1.1 Before-Concert Onboarding and Question

Hello and thank you for choosing to attend a Wellbeing Concert!

We know that people think about well-being in many different ways and we want to hear from you. If you choose to share with us, we will ask you a few questions at the **beginning**, **middle**, and **end** of the concert.

Your responses are **anonymous** and any information you provide here cannot be traced back to you. By participating, you acknowledge:

1. You are taking this survey voluntarily.
2. You are at least 18 years of age.
3. You are aware that responding to these questions is completely voluntary and you may end your participation at any time for any reason.

I consent to participation

Please take a moment to think about what well-being means for you.

With this personal understanding of well-being in mind, **how do you hope this concert impacts your well-being**?: _____

_____

_____

_____

B.1.2 Pause Screen

Thank you for your response.

Please **leave this webpage open**, but tuck your phone away and enjoy the show!
We will let you know when it is time to answer the next question.

B.1.3 During-Concert Question

Thank you for taking a moment **during the concert** to reflect on your experience.
How helpful has the concert been so far in helping you towards your well-being goal, from **1 (not helpful at all)** to **7 (completely helpful)**?

1 *(not helpful at all)* 2 3 4 5 6 7 *(completely helpful)*

B.1.4 Pause Screen

Thank you for your response.

Please **leave this webpage open**, but tuck your phone away and enjoy the show!
We will let you know when it is time to answer the next question.

B.1.5 Post-Concert Question

Thank you for attending the show.

Now that the concert is over, how helpful was it in helping you towards your well-being goal, from **1 (not helpful at all)** to **7 (completely helpful)**?

1 *(not helpful at all)* 2 3 4 5 6 7 *(completely helpful)*

Thank you for reflecting with us. We're so grateful for your presence and your time. If you are willing, we would love to hear any reflections or feedback you have from today's performance.

Feel free to either upload additional video/audio clips or provide a written response.

If you would like, please type your written response below: _____

_____

_____

If you would like, please upload your file below: Drop files or click here to upload.

B.2 Questions from the draft of the printed, hard copy pilot of the ICWAS survey from the May 23, 2023 concert.

B.2.1 Before-Concert Onboarding and Questions

Hello and thank you for choosing to attend a Wellbeing Concert!

We know that people think about well-being in many different ways and we want to hear from you. If you choose to share with us, we will ask you a few questions at the **beginning**, **middle**, and **end** of the concert.

Your responses are **anonymous** and any information you provide here cannot be traced back to you. By participating, you acknowledge:

1. You are taking this survey voluntarily.
2. You are at least 18 years of age.
3. You are aware that responding to these questions is completely voluntary and you may end your participation at any time for any reason.

Please take a moment to think about what well-being means for you.

With this personal understanding of well-being in mind, **how do you hope this concert impacts your well-being**?: _____

_____

_____

_____

Before the concert begins, how successful have you been in achieving your well-being goal in your daily life so far, from **1 (not helpful at all)** to **7 (completely helpful)**?

1 *(not helpful at all)* 2 3 4 5 6 7 *(completely helpful)*

B.2.2 During-Concert Question

Thank you for taking a moment **during the concert** to reflect on your experience.

How helpful has the concert been so far in helping you towards your well-being goal, from **1 (not helpful at all)** to **7 (completely helpful)**?

1 *(not helpful at all)* 2 3 4 5 6 7 *(completely helpful)*

B.2.3 Post-Concert Question

Thank you for attending the show.

Now that the concert is over, how helpful was it in helping you towards your well-being goal, from **1 (not helpful at all)** to **7 (completely helpful)**?

1 *(not helpful at all)* 2 3 4 5 6 7 *(completely helpful)*

Thank you for reflecting with us. We're so grateful for your presence and your time. If you are willing, we would love to hear any reflections or feedback you have from today's performance.

Feel free to either upload additional video/audio clips or provide a written response at the link: [redacted]

Appendix C

The Distance Between Us Score

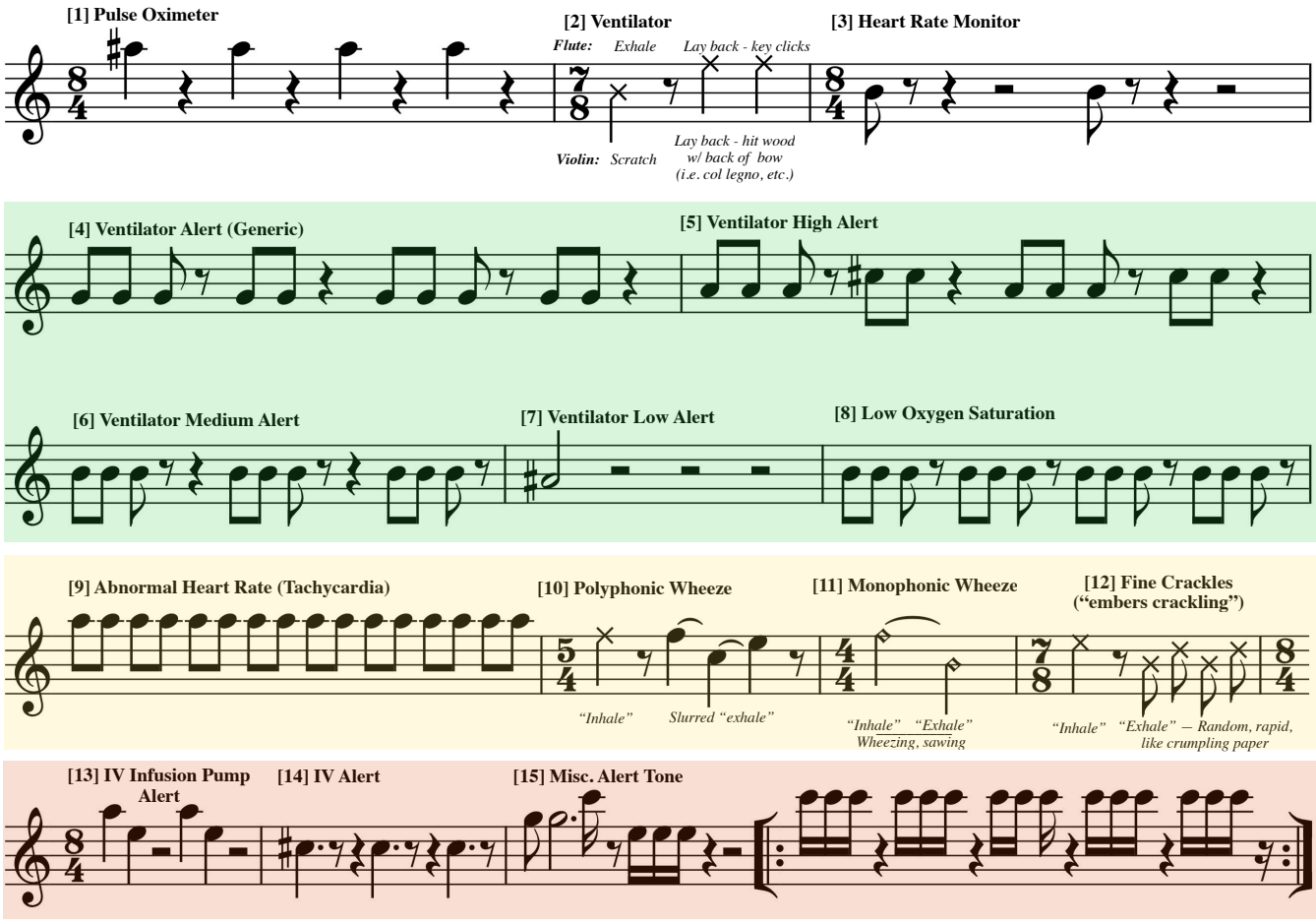
The Distance Between Us

For Jessica Shand and Charlie Lovell-Jones
By Kimaya Lecamwasam

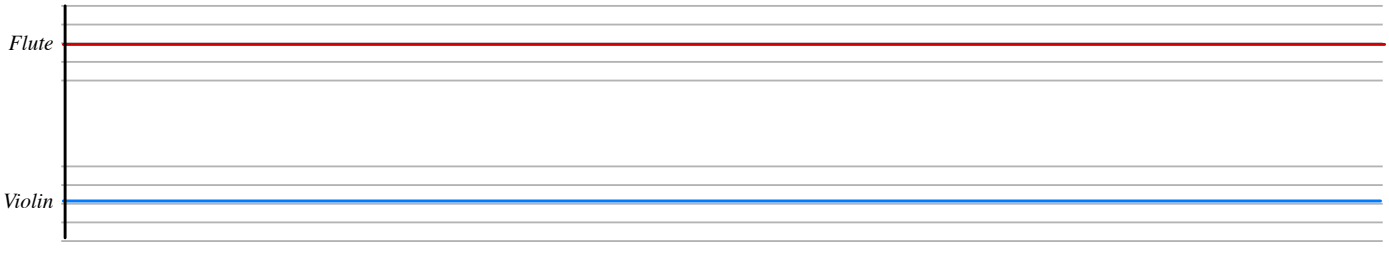
AT THE START: Each instrument chooses to replicate the rhythm of a pulse oximeter, a ventilator, or a heart rate monitor. For the first 1-2 minutes, rhythm and pitch remain consistent, and the instruments play in harmony. After a lull has been reached, change pitch or tempo slightly and briefly and then return to "baseline." Add abnormalities as desired, at first sparingly and then with increasing frequency. As time passes, rhythm may stretch and flex into a distortion of the base sounds.

AT THE MIDDLE: Suddenly, both instruments diverge, whether in pitch, rhythm, or tempo. Each instrument is encouraged to initially shift from the normal monitoring sound ([1]-[3]) to the abnormal one ([4]-[8]), as this is a direct reflection of what happens to severely ill COVID-19 patients in the ICU. Improvisation à la Pauline Oliveros is encouraged from hereon out: "Anything goes as long as you are listening." Distortion is welcome. You are also welcome to lean into silence or steadiness at times, though ideally never for long. Preferred sounds are highlighted in green, secondary in yellow, and other options in orange. Specific events are notated in the score from page 6 onwards.

AT THE END: Slowly, gradually, the instruments return to each other and to their initial patterns, though the same level of imitation is not required. They do not regain the same level of accord as they held at the beginning. There is hesitancy. One may fall behind or pull ahead of the other, but they're working, slowly, to return to normal.



1-2 min, steady state [1], [2], [3]. Constant rhythm, create a lull.



NOTE: In this piece, lines on the staff represent dynamic baseline, NOT constant pitches.

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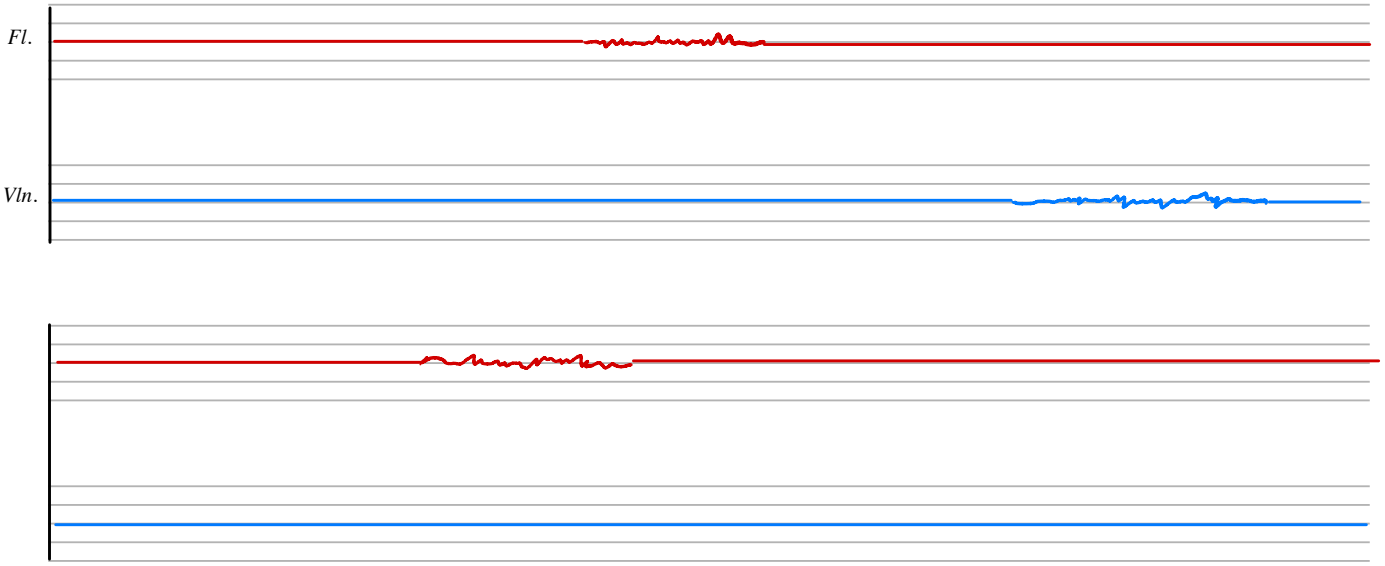
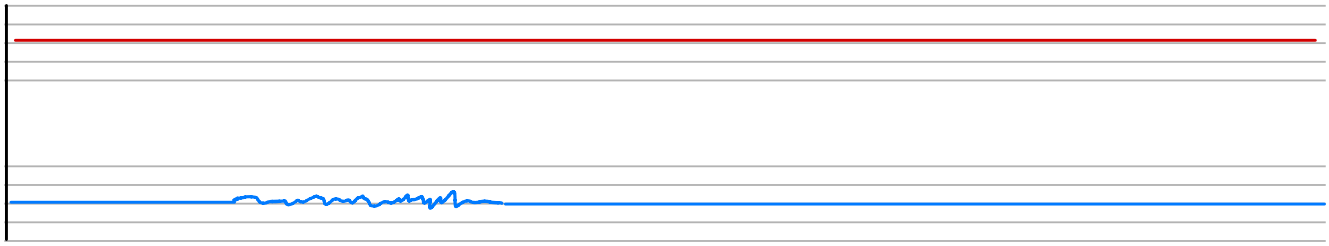
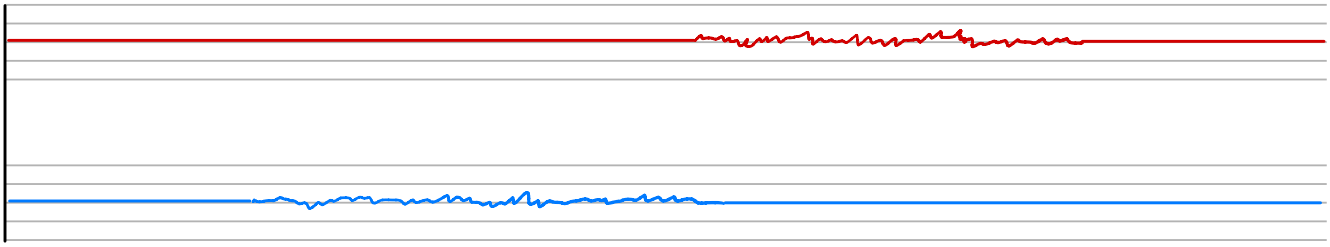
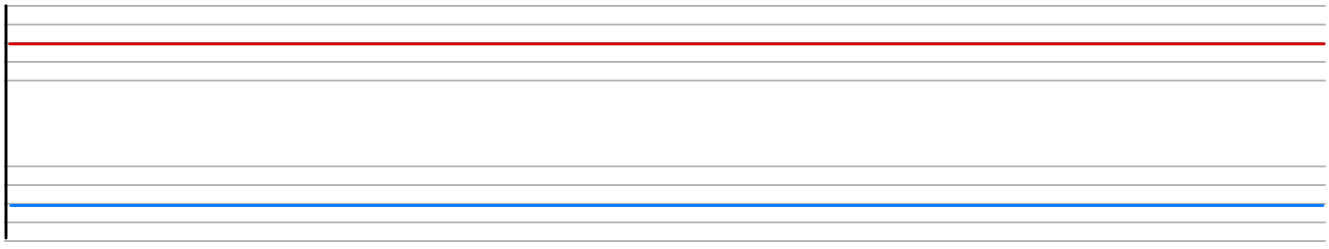
3-4 m, baseline to slight var. in pitch, rhythm, tempo, etc. (sparingly here) Build anticipation subtly.



Increase var. slightly (I.V. S.)







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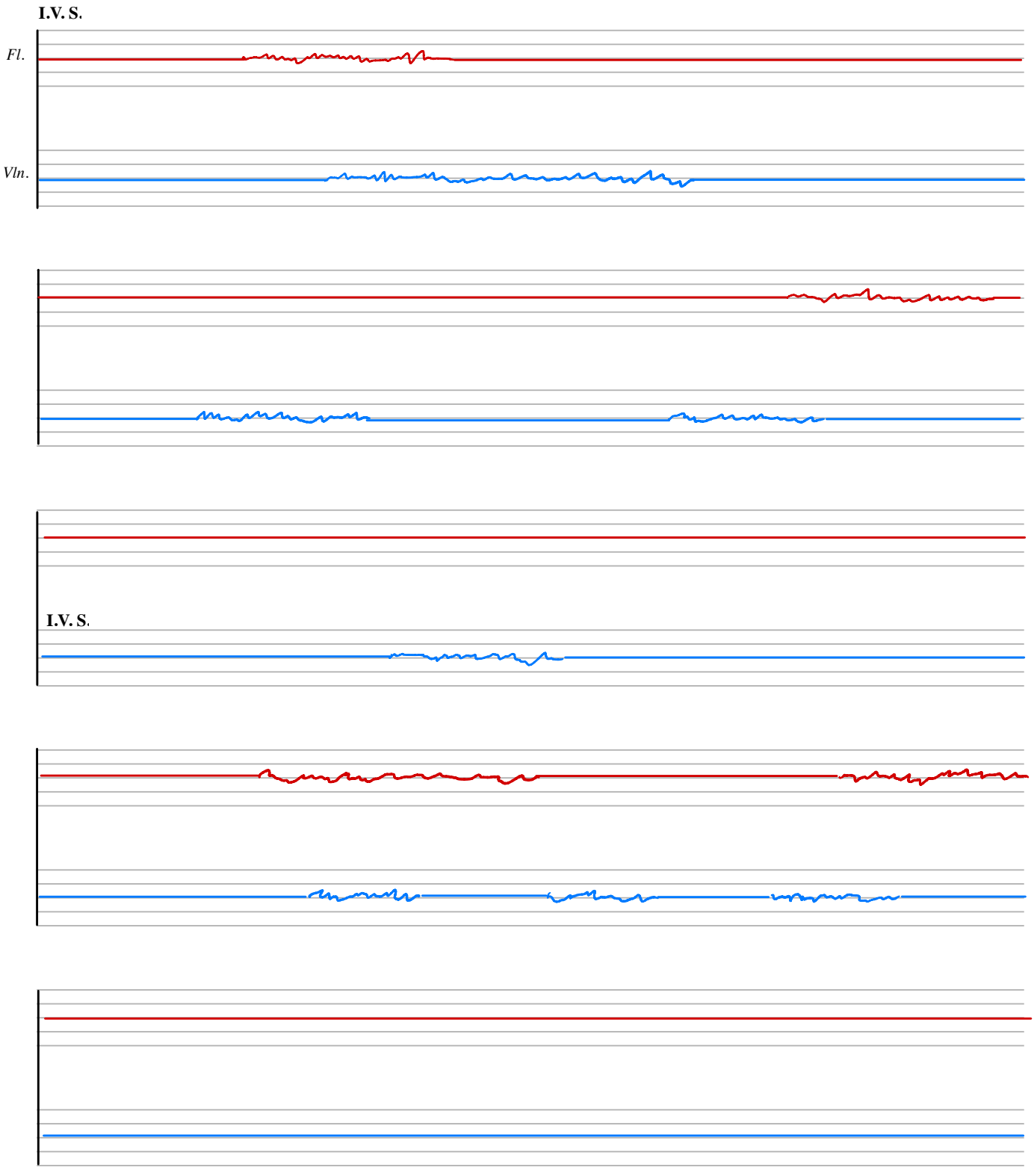

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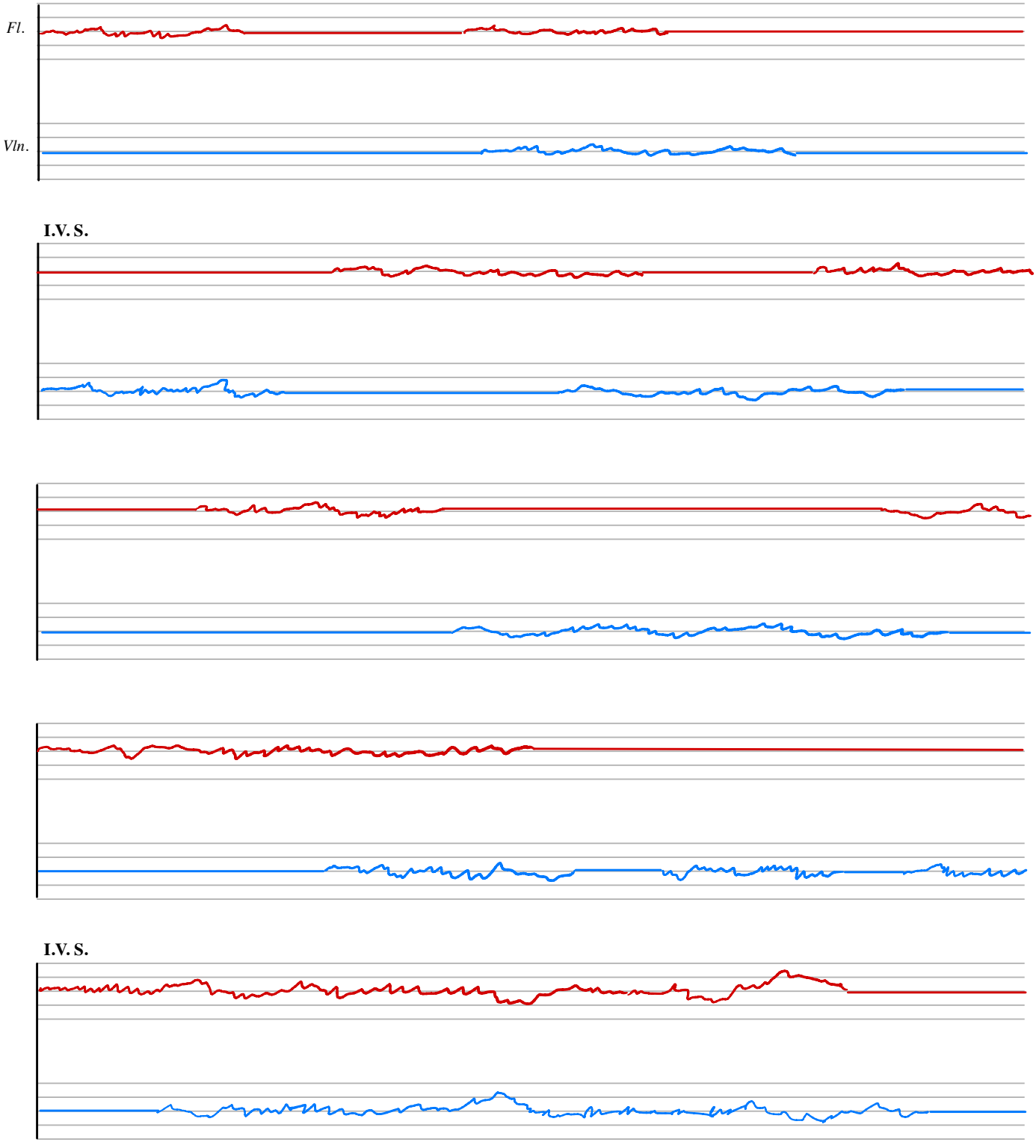

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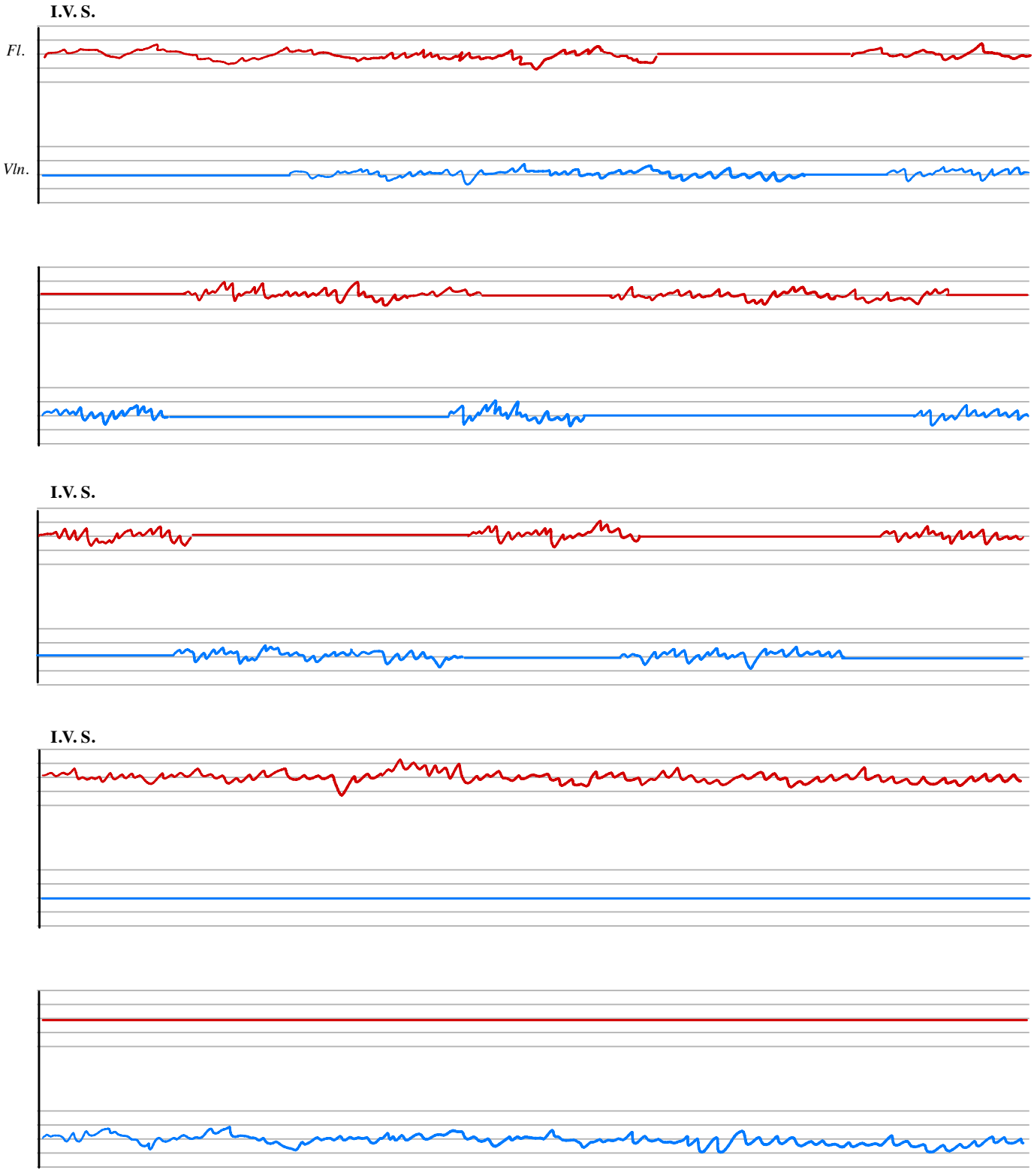

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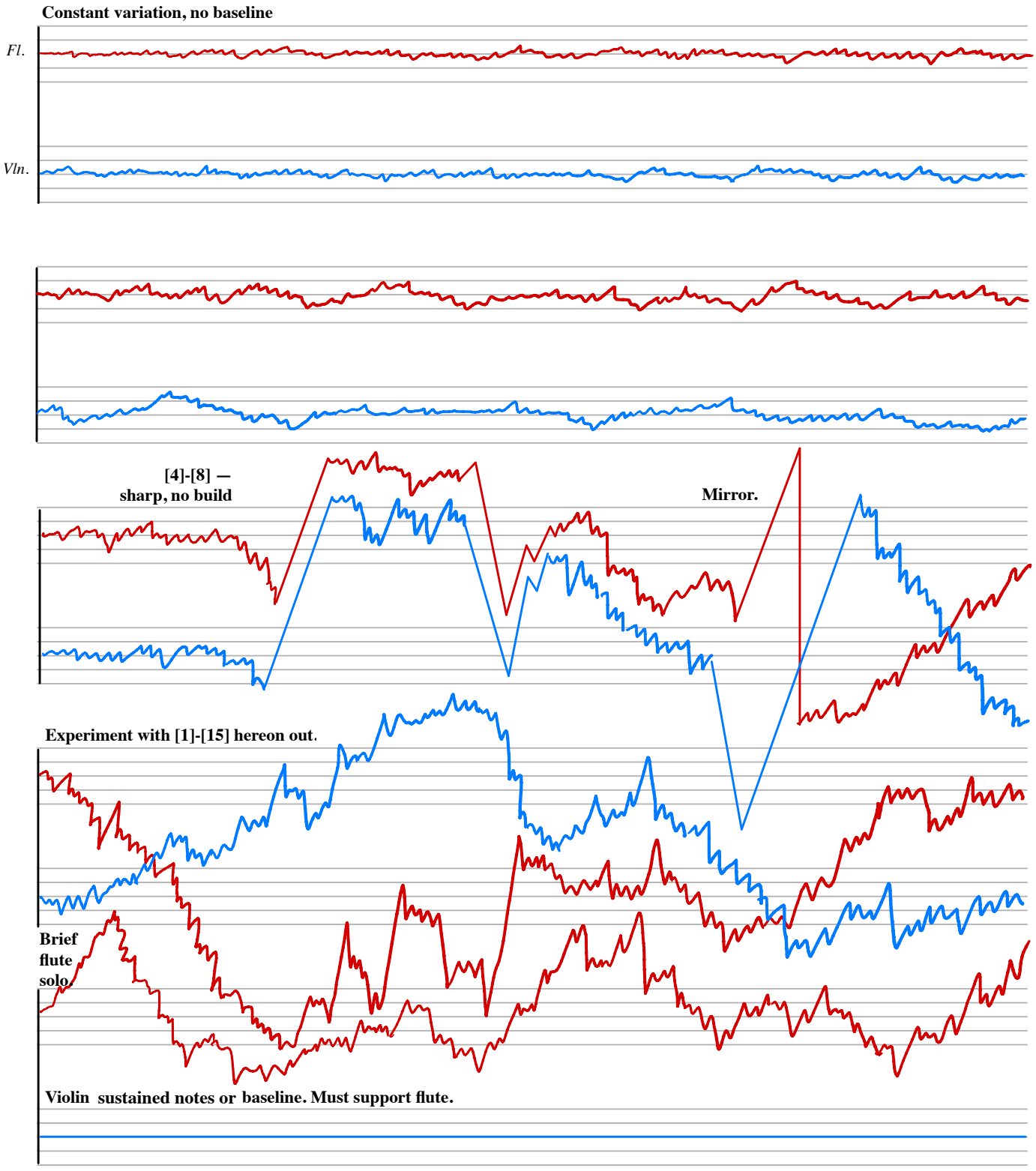

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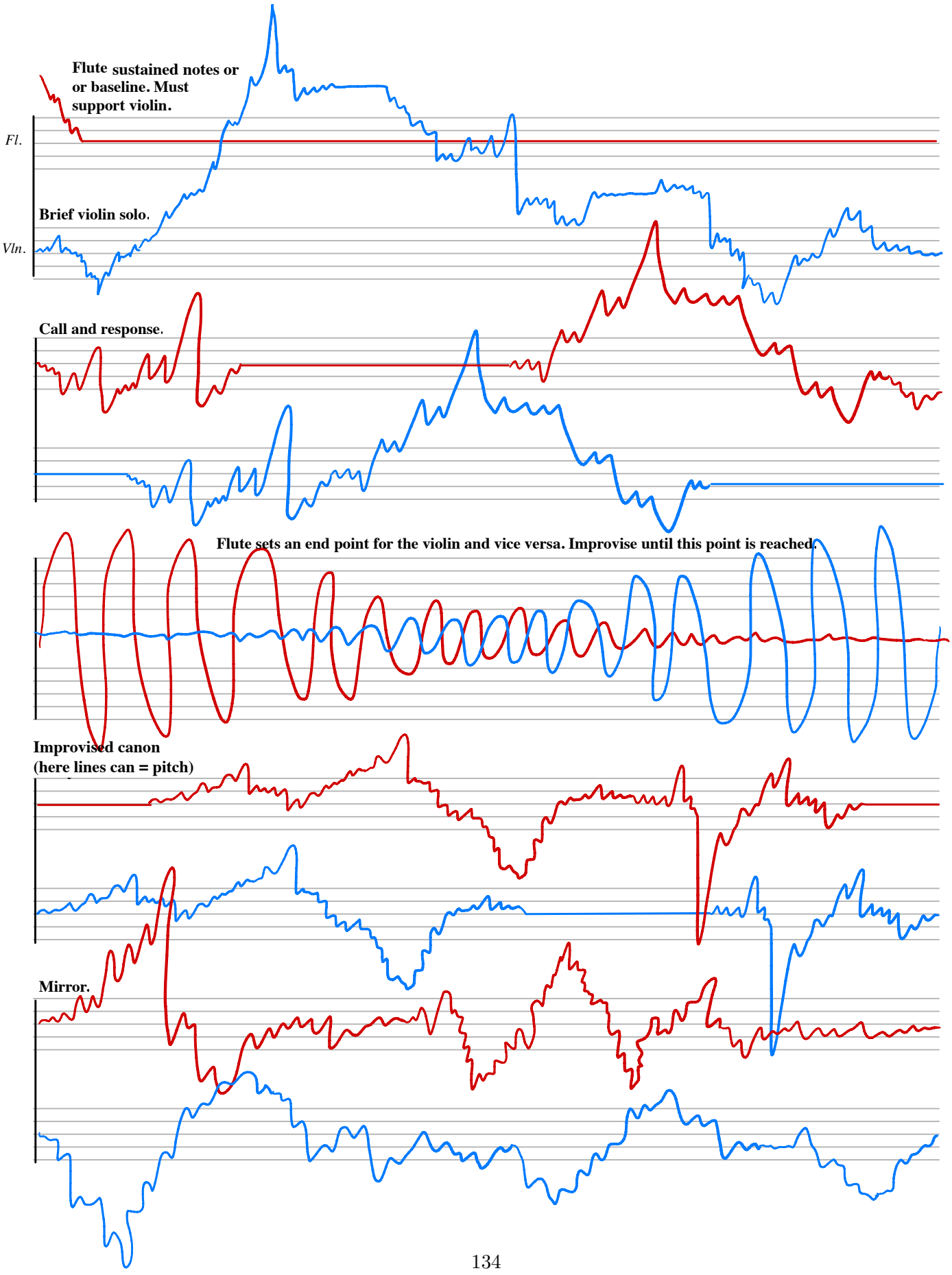

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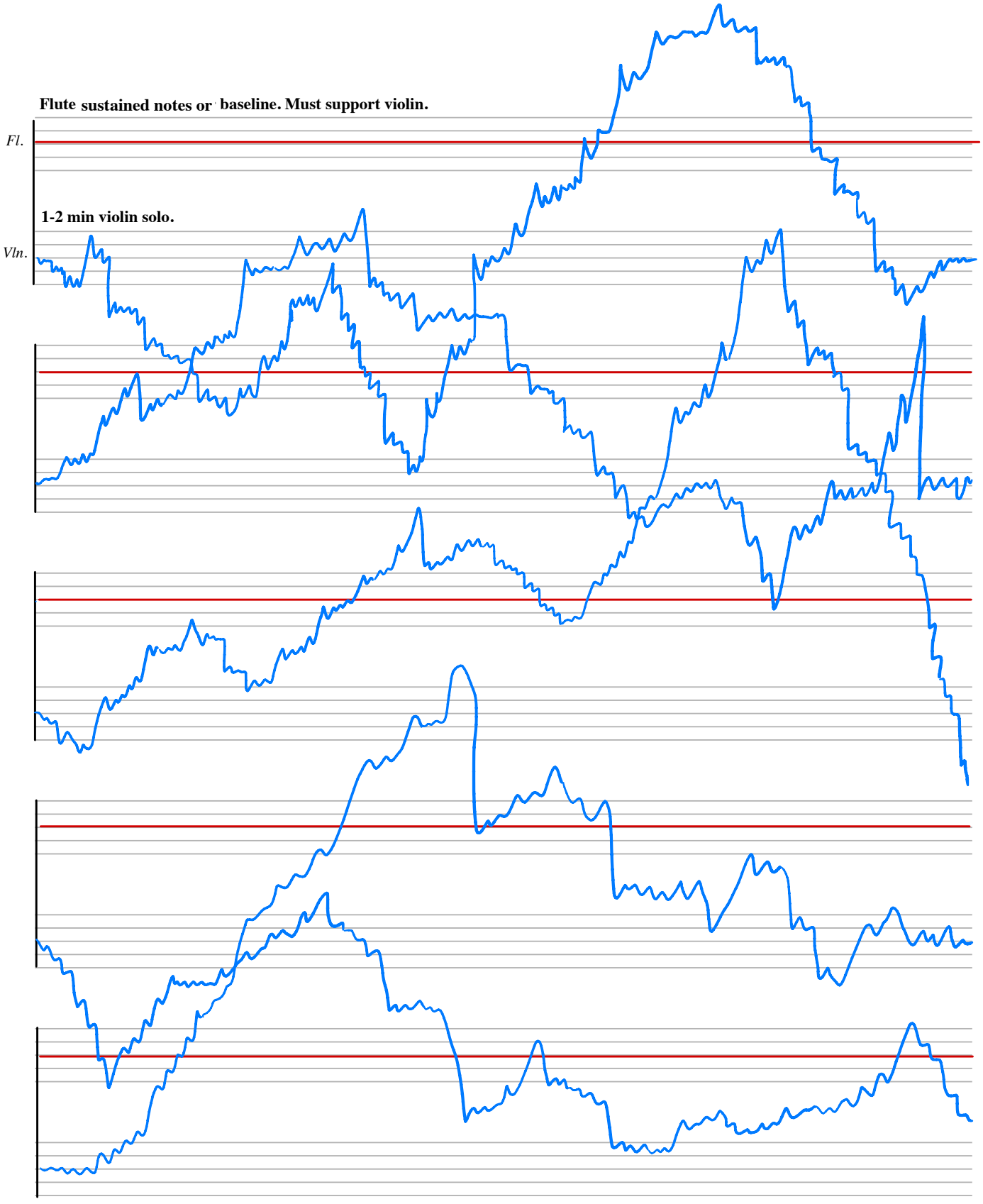

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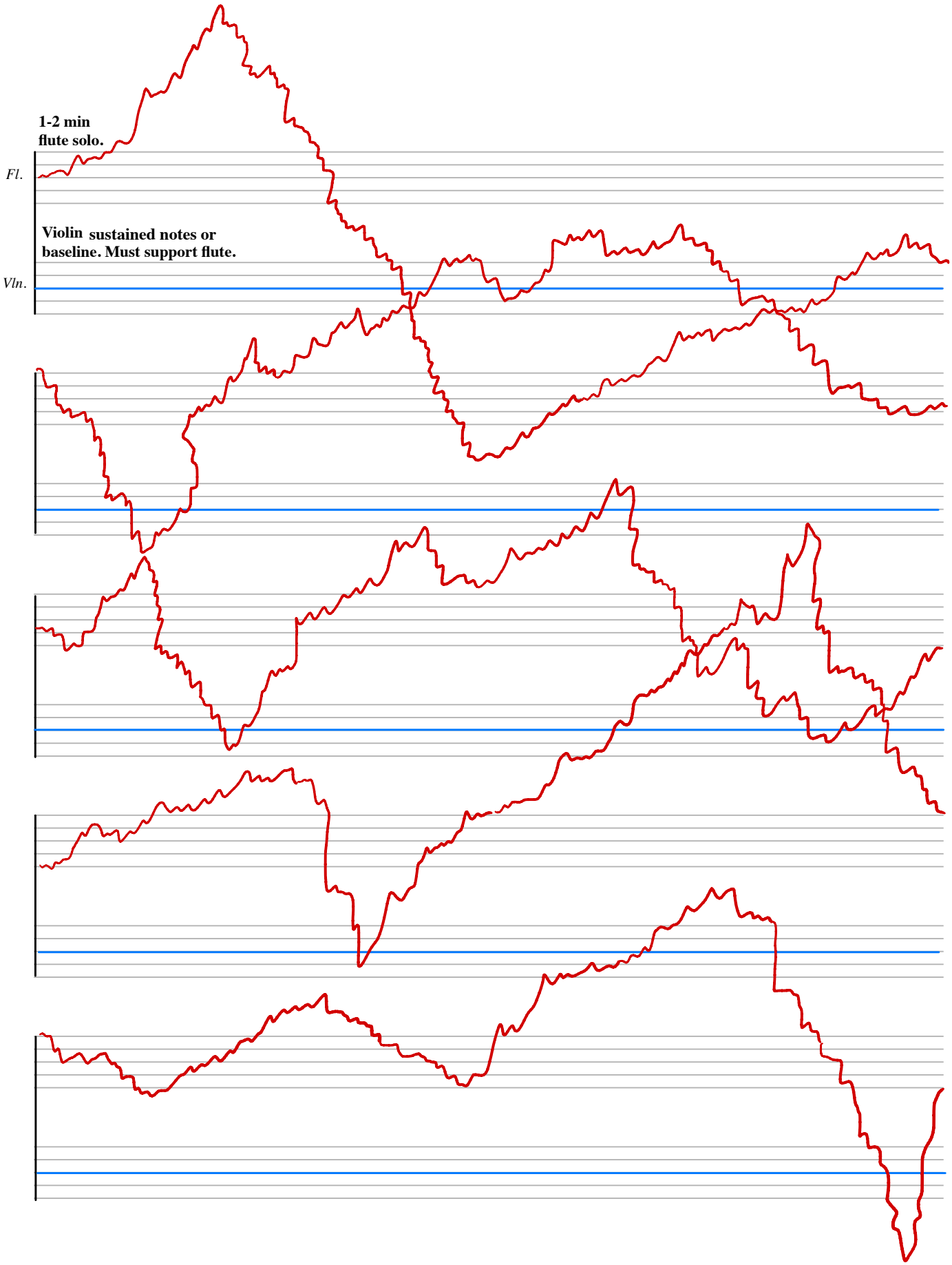

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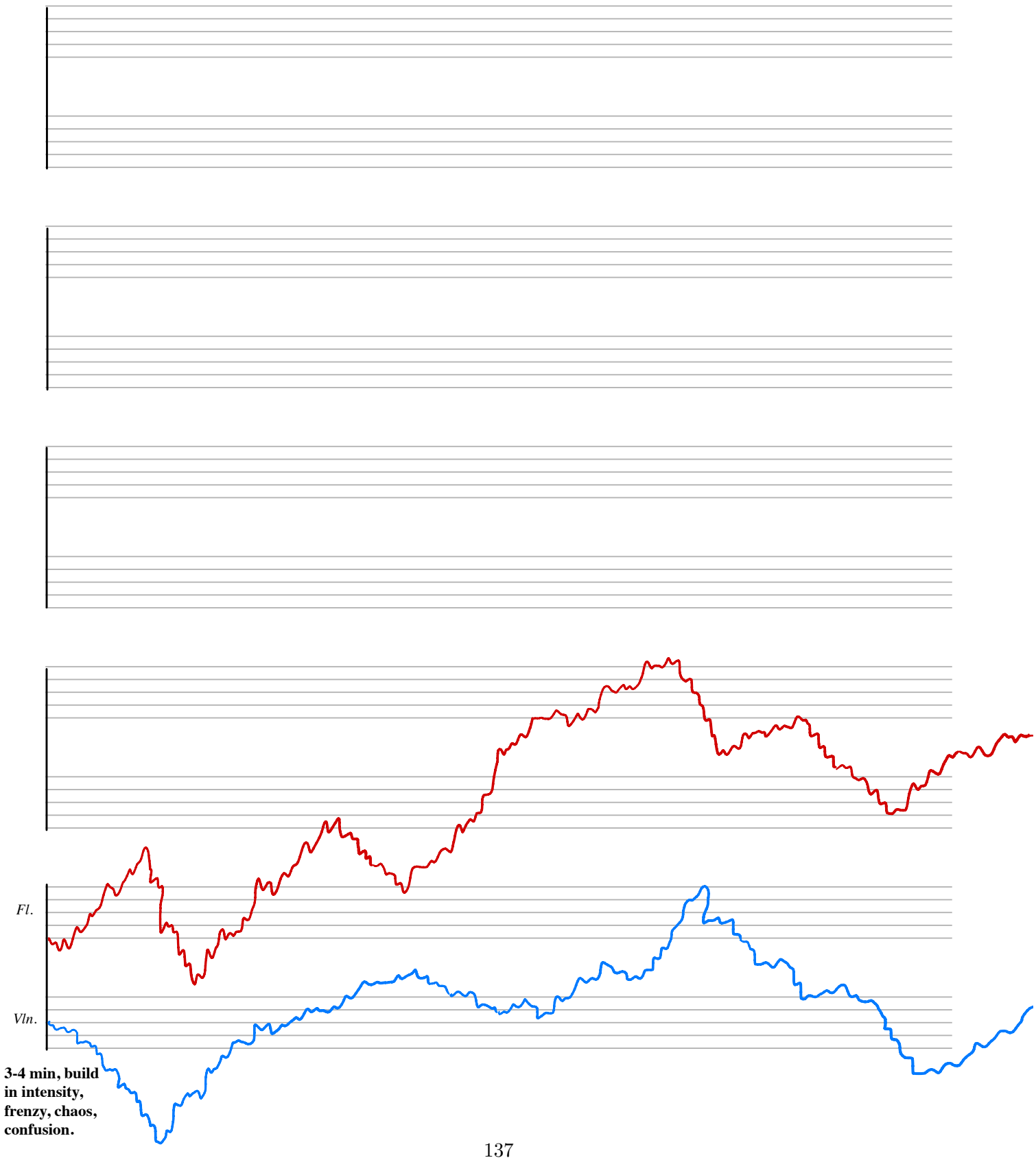

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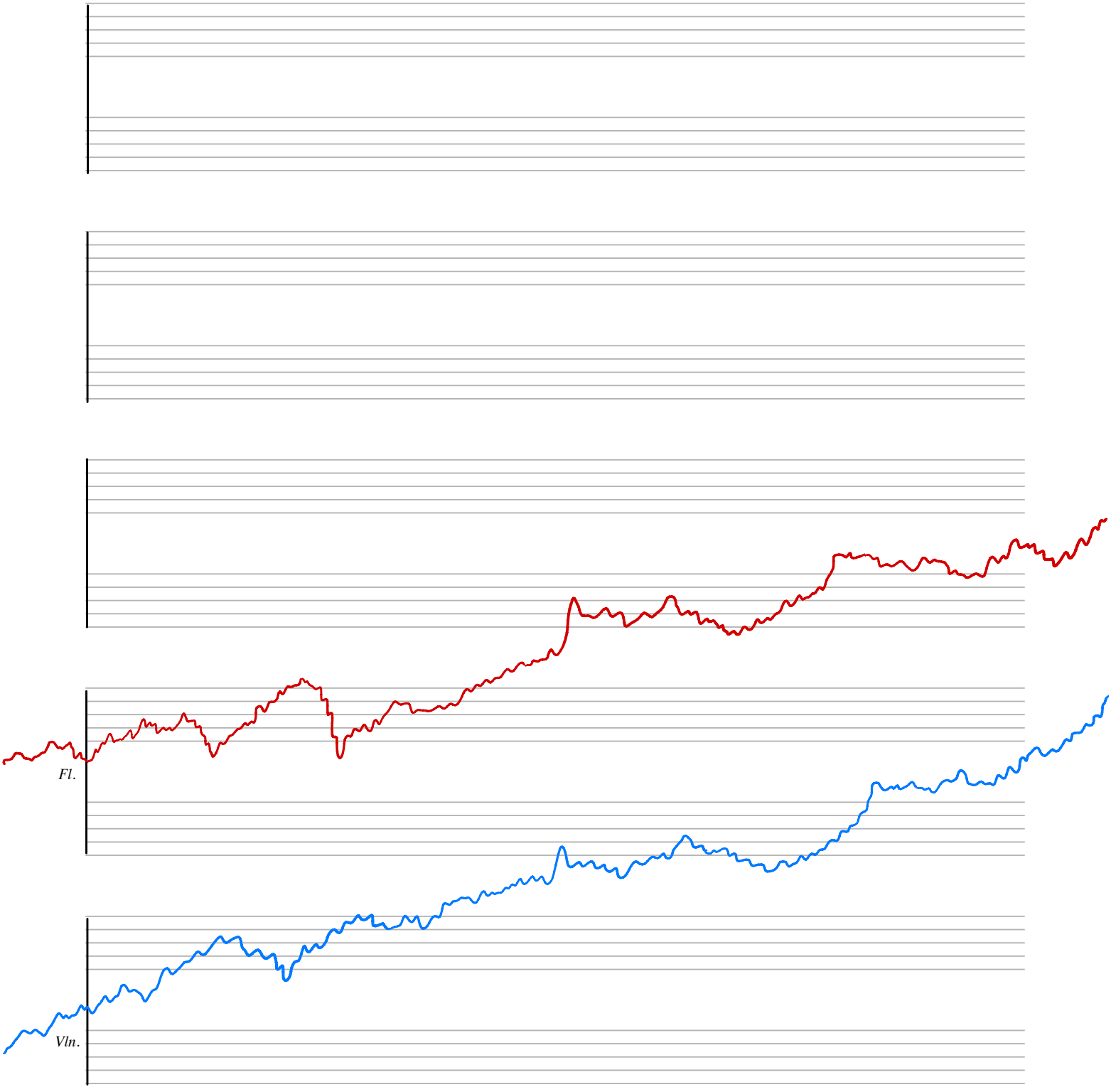

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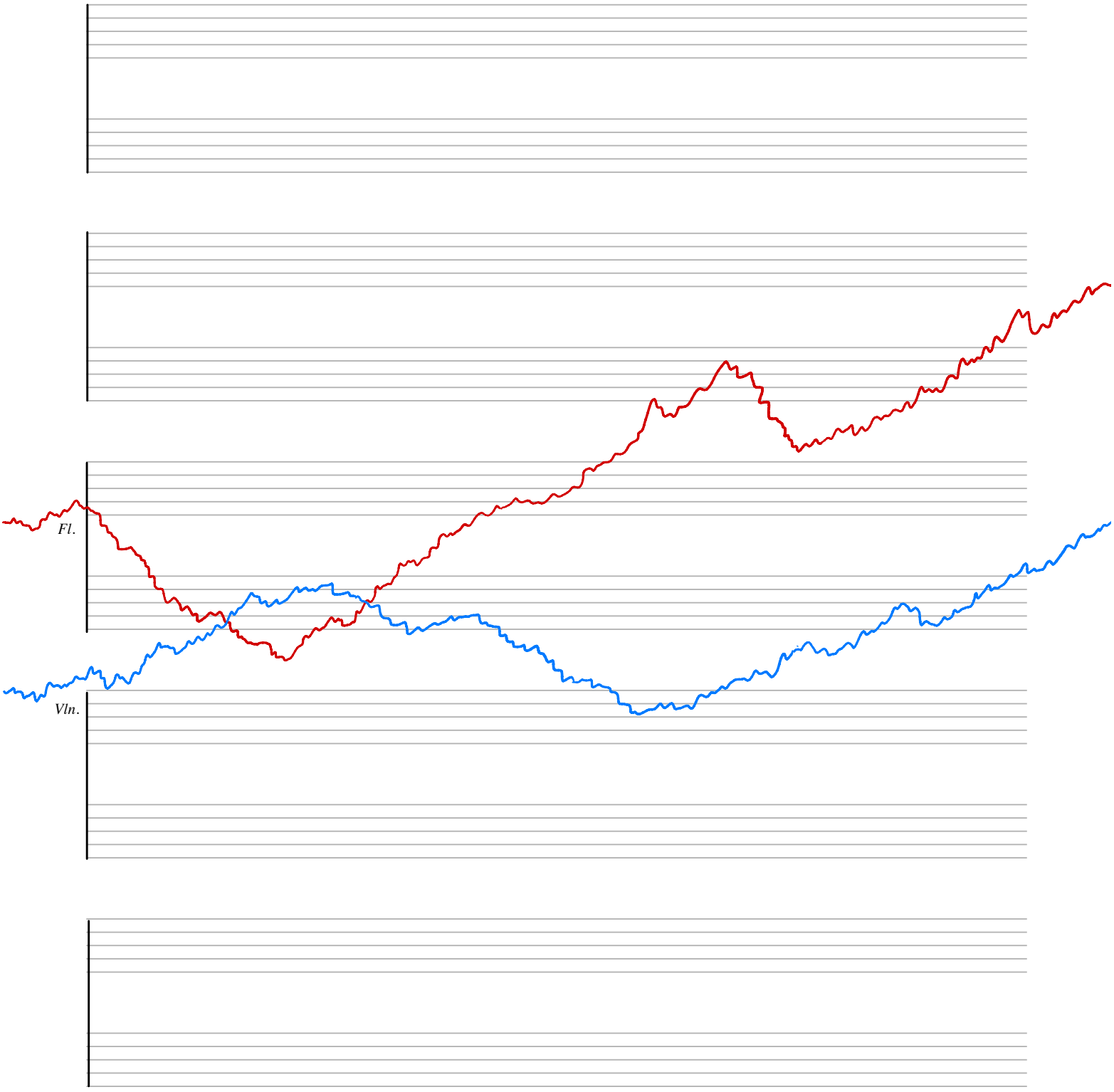

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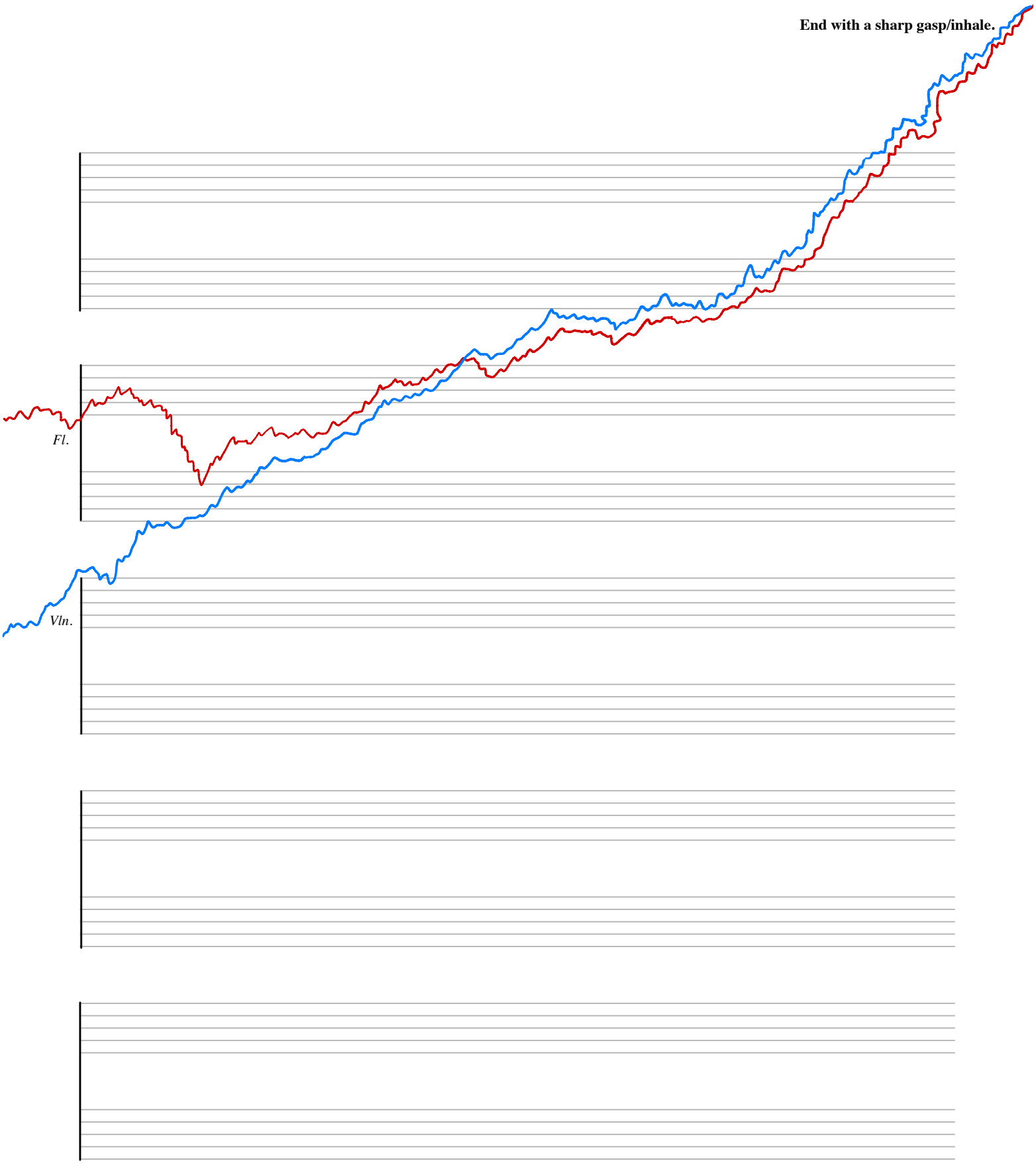

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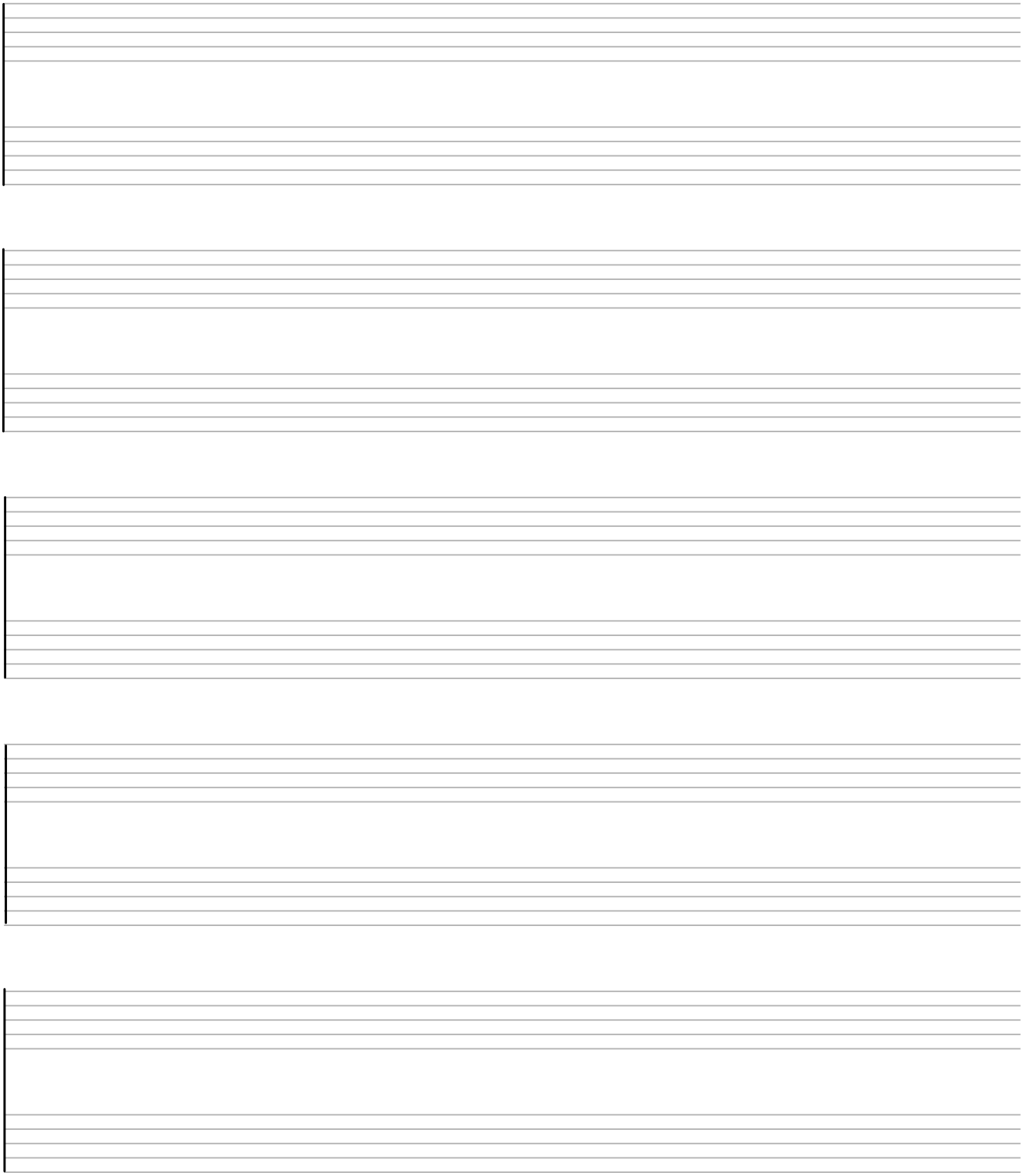
30 seconds of silence. Breathe heavily in the interim.



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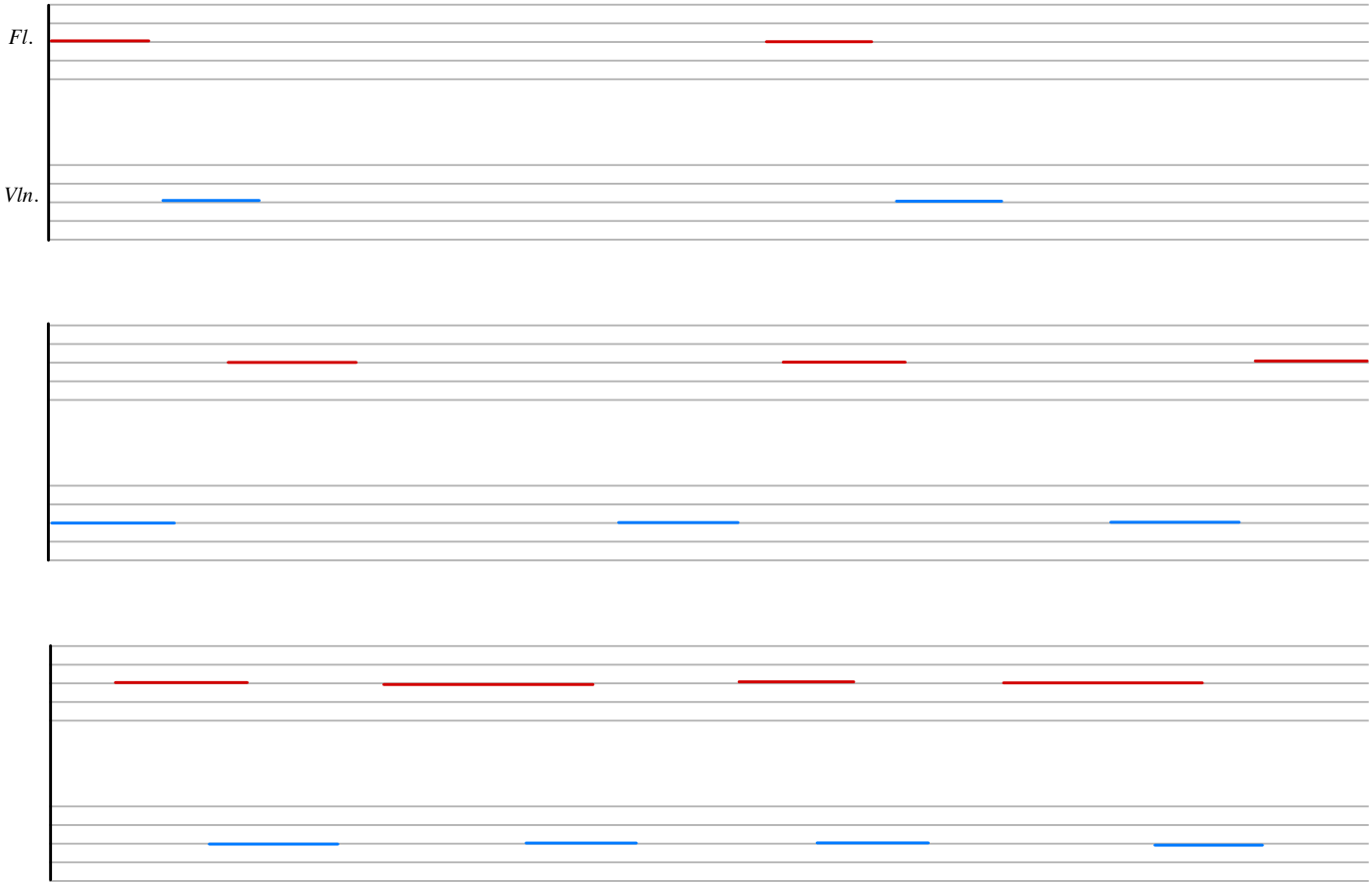
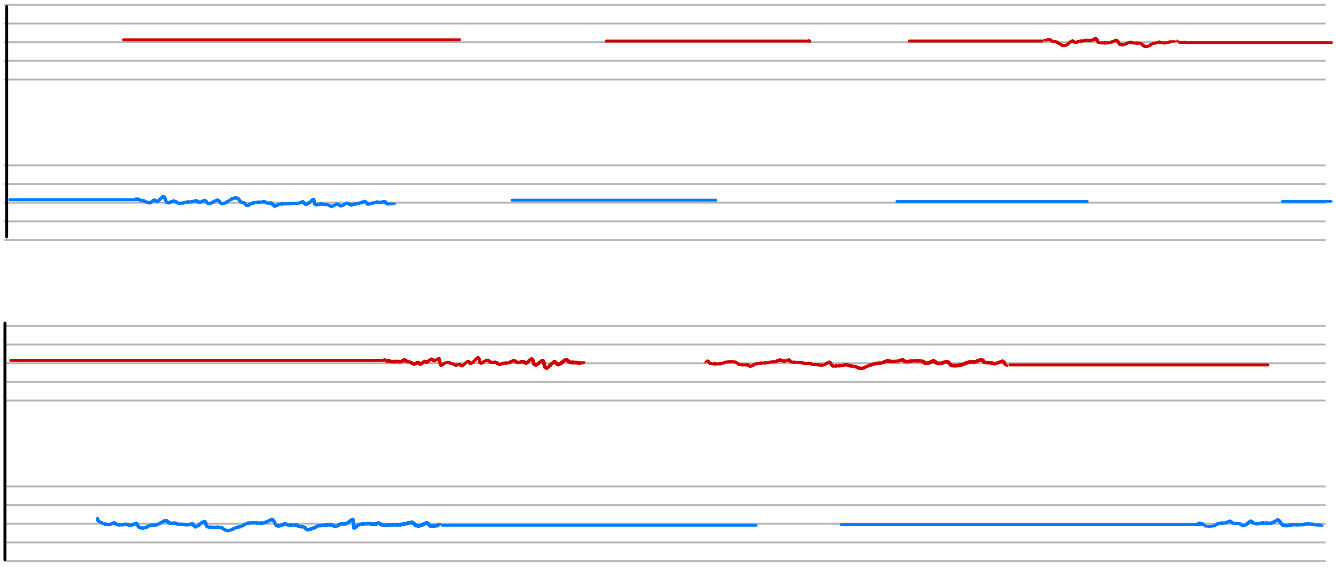
2 min, note by note build to baseline — slowly, gradually, hesitantly.



Longer phrases - small deviations in pitch, rhythm, tempo, etc. from baseline.



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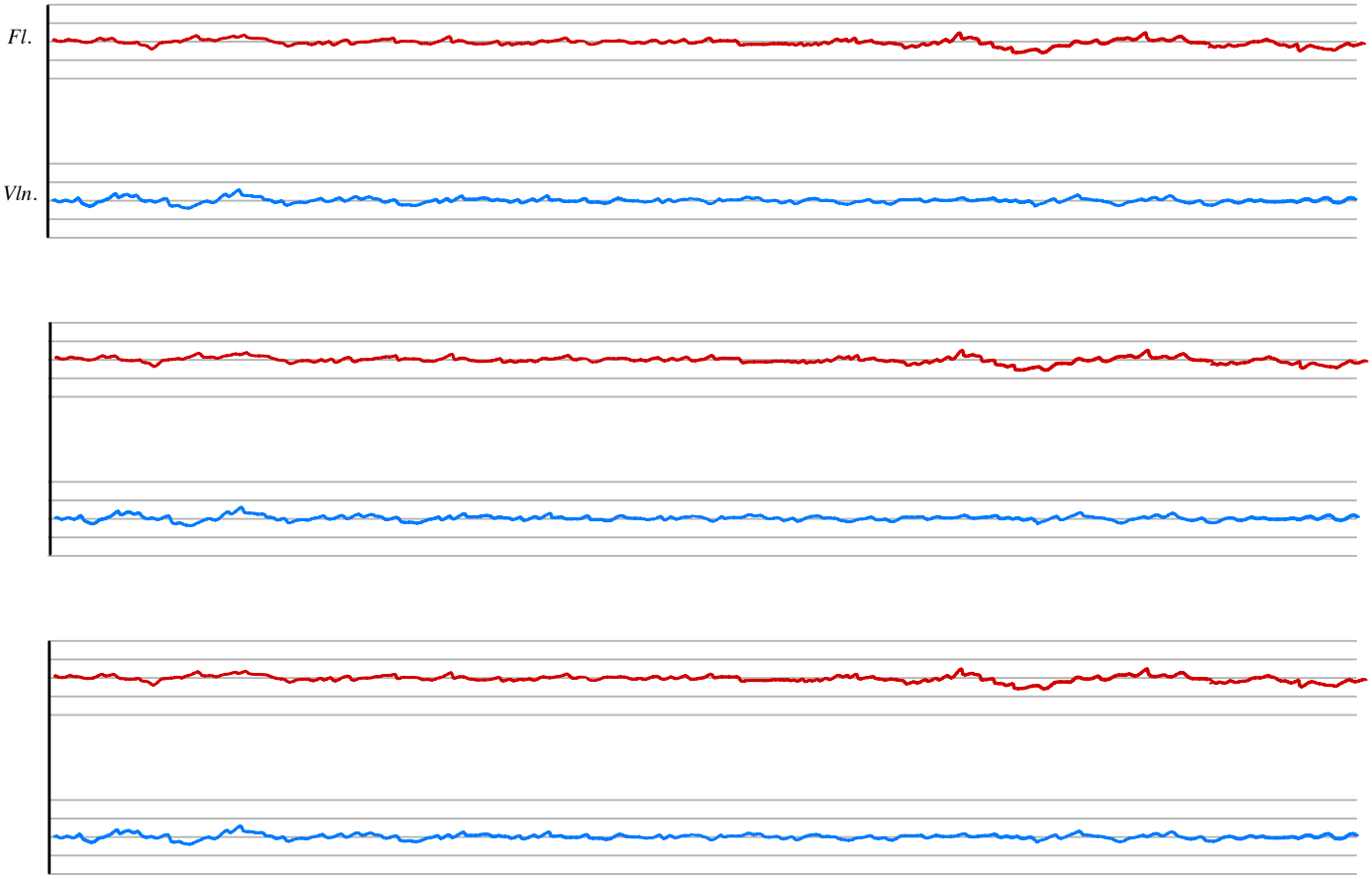
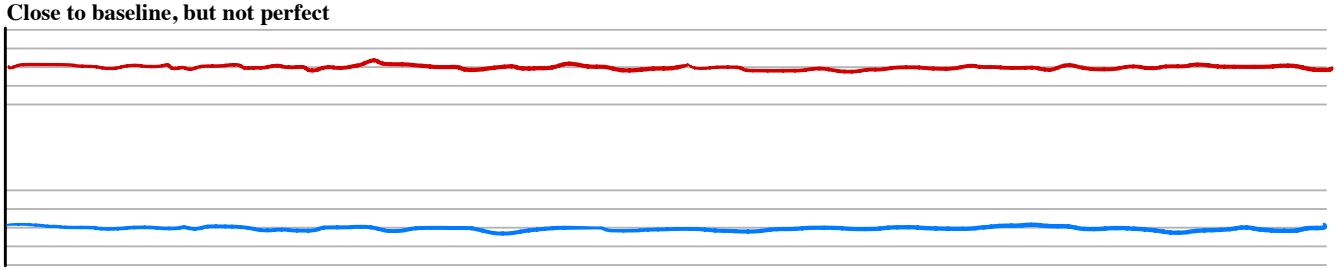
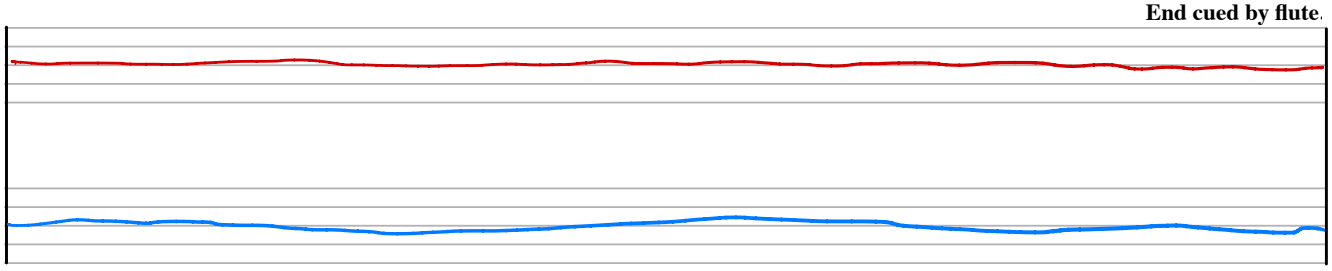


Close to baseline, but not perfect



Hold until impossible.
End cued by flute.



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Appendix D

The Distance Between Us Survey Responses

Table D.1: Participant responses to pre- and post-concert question of the *The Distance Between Us* survey. **The pre-concert question was as follows:** "We know that the relationship between music, well-being, and emotion processing differs greatly from person to person. Please take a moment to think about what this relationship means to you. With this in mind, what do you believe the emotional effect of a musical composition written about COVID-19 should be? **The post-concert question was as follows:** "At the beginning, you mentioned that the emotional effect of a musical composition written about COVID-19 should be: "[Response from Pre-Concert Question]." Please reflect on your experience at this performance. What would you change to bring you closer to this goal? What would you keep the same? What did you think in general?" Italicized responses were removed from consideration.

Participant	Pre-Concert Response	Post-Concert Response
1	Sad but cathartic	It was a great piece and very moving. It made me feel very chaotic and uneasy, because of all the sounds and rhythms and pitches coming from different times and places, and the energy of the performers. For me there was a sense of relief at the end. For me, the time of Covid felt more like a dull sadness, acceptance, and ultimately transformation that was not as chaotic, but I think this piece very clearly captures a different way of experiencing the pandemic that I really appreciated.
2	Hmm good question, on the one hand, it might be good for a piece to help with healing and helping reflect peacefully on the experience. On the other hand, to truely [sic.] bring us back in the emotional effect of covid [sic.] maybe the sheer anxiety and stress and tantalizing effect of the pandemic would be the most effective	The piece was particularly intense and quite anxiety-inducing and brought very raw feelings. Maybe it was missing a little bit of hope? I also felt like the piece brought a lot of uncertainty about when it would end, due to how the tension was spread through the different movements. This somehow was also very true of the pandemic. We just didn't know when it would end for the longest time. That rang really true to me. But also quite stressful. I am not sure i am really answering the question about what I would change but this it how the piece felt

3	COVID-19 was obviously a very challenging episode for many people, as well as having a very deep emotional charge. The emotional response, to me, encapsulates feelings of fright, anxiety, darkness, and loss of hope, associated to the comfort of one's home, and the pleasure of spending time with loved ones. As such, I believe that the composition should reflect all those conflicting feelings.	The dynamic of the performance really captured these ambiguous feelings, with great diversity of sounds played by both instruments. I got very moved by the use of Jessica's loud breaths during the performance, and I really believe that human voice, even more in the middle of a purely instrumental piece, brings a great emotional charge. All of the feelings I described earlier could maybe be even more accentuated through more use of the voice.
4	A reflection of the emotional arc that COVID was for each of us. From not thinking it will affect us, to being afraid, anxious and eventually with the vaccines, polarizing messages, relearning normalcy. Also another aspect could be the effect of suffering from COVID, the panic, the loss of smell, coughing etc as elements in the music. A musical composition could take me on these emotional journeys through the way it evolves.	I loved the beginning and ending that really captured what I was imagining especially the heavy breathing that led to the motif at the end. I was thinking about the narrative of COVID while listening to the entire performance and felt the isolation and tension rise and fall through the piece. The two instruments sounded like two characters and I would be interested in hearing the isolation of the two sonic worlds from each other to remind me of the COVID isolation. Perhaps a spacialization [sic.] could increase of decrease the effect of the sounds! Thank you!
5	Explore isolation and connection	After hearing the piece, i heard another metaphor emerge, which is that of waves. Tension and release. The tension built finally towards the end when the players reached the climax and then gasped for breath. The short rythmic [sic.] pulses reminded me of the passage of time, such as in an ICU ward or in isolation at home alone.

6	Breaking the feeling of Isolation/ feeling a new connection	I would not change anything. There are so many elements to reflect on ! The performers have a strong connection while performing. The feeling of isolation and attempts to be connected seem visceral.
7	Healing and connection... but I think it also should speak to distance in a new way. It's hard to say something about the pandemic as a whole that feels resonant and not generic... but I think speaking to individual experience, speaking to the realizations we all had and the ways that our communities were affected rather than the numbers, seems most powerful. So... I would expect or hope to connect to the composer on a personal level, and to feel that transition between a sinking feeling—a grief we still don't know how to fully process—and something maybe not more hopeful, but still raw and real. We never really finish processing, and I think reflecting that while still feeling like a complete narrative is something I would hope for in a composition like this.	First... this was beautiful. Things really began to click for me near the very end, when both performers drew strained breaths. At that point, the meaning of the piece began to set in. I think it was especially poetic given that these kinds of experiences only make sense in retrospect. The connection between the performers was also powerful all throughout—it felt like it really tied the narrative together, the idea of these two forces within one person trying to recover, or two people on parallel journeys through illness and trauma. I initially found it difficult to relate to, but it eventually sunk in that these were sonifications of data from the ICU. I found myself trying to imagine myself in that space, and although difficult (because I'm used to thinking about the pandemic from a mental + emotional rather than physical standpoint, which feels like an incredibly privileged thing to be able to say), what I arrived at was the amount of time one might have to think... and how splintered that process might be by waves of well-being (or a lack thereof). The ways in which sonifications moved into moments of climax and quiet felt like a meditation, similarly to how we allow our thoughts to move through us. I don't know that this should move closer to my original goal—I think it achieves showing a very different and very raw perspective on the pandemic than my own.

8	It should be about communication, compassion and hope.	I loved the performance. I wished they somehow communicated us eye-to-eye as they were performing; reflecting the communication aspect of my response.
9	release of bottled up emotions leading to feelings of comfort and acceptance about the loss of lives/missing out on opportunities/what we all went through.	damn kimy that was amazing! I loved the way that the flute and violin created both mechanical and human sounds and really like, close your eyes and you're there you know. love the movement on stage and also the eye contact - makes me think about when we would see pictures of people on ventilators taking selfies and stuff and I feel like I really was feeling how they felt
10	Hopeful and help uplift.. I used music throughout covid [sic.] to help center me and give energy.	I thought it was a very thoughtful rendition of someone going through a very tough time in the ICU.. it was very beautifully done.. I loved it.. but made me sad
11	Give space to process complex feeling like grief or loss.	I really enjoyed it - I thought it was really lovely and at times reminded me of specific moments or feelings I had during COVID, occasionally it felt a little theatrical (I think some of the gasping moments but overall it felt really honesty [sic.].
12	Hope inspiring	I think the beginning and the climax was really indicative of COVID and the end provided the hope. It would have been good to have a bit calmer music at the end. I was really impressed by the way the disease progression was captured.
13	*Absolutely*	Fantastic
14	The angst, the uncertainty followed by the hope and ensuing ability to vanquish the disease	Amazing composition. Loved the way it starts and the way it comes together in the end

15	Chaotic and reflective. something silent and angry. I feel like a lot of contraries	It was captivating completely. The breath work in the piece was particularly interesting. I thought the piece was complete in its delivery and couldn't think of anything that could make it ANY BETTER. Love it.
16	Hope for the future!	*Give us a carrage [sic.]!*
17	i think it could be unsettling at first, abrupt, but also feel homey at some point.	I loved it! I think it was not about my experience in covid, but at the dame [sic.] time found it relatable
18	tension & anxiety, grief, but also catharsis and a sense of resolution	i think the breathing and the percussive technique really bring forward the themes the piece presents. i also feel the uncertainty of not knowing how the rest of the next few days, let alone the night, will go. slay
19	Serious with hope	Well done. Great!!
20	Emotional, sad, but hopeful	I loved how the piece reflected the stress, uncertainty, and unpleasantness of the situation. The shrill tones that came out at certain points reinforced this. I wish my first answer would've considered this element of the emotions present. I wouldn't change the piece - it was evocative and shocking. And beautiful.
21	Celebrate survival	That was amazing. Amazing

Appendix E

Music, Stress, and Anxiety – Pre-Study Questionnaire

E.1 Demographics

1. Participant code (researcher only): _____
2. How old are you?
   (a) 18-28
   (b) 29-39
   (c) 40-50
   (d) 51-65
   (e) 66-75
   (f) 76+
3. Sex assigned at birth?
   (a) Female
   (b) Male
   (c) Intersex
   (d) Other/prefer not to say
   (e) Other: _____
4. Does the above answer align with your current gender identity? If the answer is "no", please self-describe in other if you are comfortable.
   (a) Yes
   (b) No
   (c) Other: _____
5. Do you enjoy doing math?
   (a) Yes
   (b) No
6. Do you prefer:

(a) Mental mathematical calculations?

(b) Written mathematical calculations?

7. What is the highest level of math that you have studied?

   (a) Algebra

   (b) Pre-Calculus

   (c) Calculus

   (d) Differential Equations

8. Do you feel that competition hurts/harms your performance?

   (a) Yes

   (b) No

9. Do you use music to relax?

   (a) Yes

   (b) No

10. If "yes", please describe the music you use to relax: _____

11. If "no", please explain why you do not use music to relax: _____

12. Do you have any musical education?

    (a) Yes

    (b) No

13. If "yes", please briefly describe your musical education: _____

14. What is your favorite type of music?: _____

E.2 Current Anxiety and Stress (CAS) Questionnaire

Please indicate your current level of **stress**:

1 *(not stressed at all)* 2 3 4 5 *(extremely stressed)*

Please indicate your current level of **anxiety**:

1 *(not anxious at all)* 2 3 4 5 *(extremely anxious)*

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Mental Health Resources

- General Emergency Resources:
  - Massachusetts General Hospital Acute Psychiatric Services (APS): 617-726-2994
  - Cambridge Health Alliance: 617-665-1560
- MIT Specific:
  - MIT Medical Student Mental Health and Counseling: 617-253-2916 (days), 617-253-4481 (nights and weekends)
- Harvard Specific:
  - Counseling and Mental Health Services 24/7 Helpline: (617) 495-2042

E.3 Generalised Anxiety Disorder Assessment (GAD-7)

How often have you been bothered by the following over the last **three days**:

	Not at all	**Mild**	**Moderate**	**Severe**
Feeling nervous, anxious, or on edge	☐	☐	☐	☐
Not being able to stop or control worrying	☐	☐	☐	☐
Worrying too much about different things	☐	☐	☐	☐
Trouble relaxing	☐	☐	☐	☐
Being so restless that it is hard to sit still	☐	☐	☐	☐
Becoming easily annoyed or irritable	☐	☐	☐	☐
Feeling afraid, as if something awful might happen	☐	☐	☐	☐

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